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Final Report on Contract NAS 5-9090
Processing and Analysis of Data from
the University of Chicago Experiments on the
IMP 4 and 5 Spacecraft

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(NASA-CR-130171) PROCESSING AND ANALYSIS
OF DATA FROM THE UNIVERSITY OF CHICAGO
EXPERIMENTS ON THE IMP 4 AND 5
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Data from the Charged Particle Experiments on the IMP-4 and 5 spacecraft were processed and analyzed from launch ⁽¹⁾ through re-entry ⁽²⁾. Approximately 95% of all data transmitted was recovered ⁽³⁾. All recovered Data was processed and analyzed. The University of Chicago experiments performed normally throughout the spacecraft lifetimes.

Section I below outlines the computer programming and operational procedures which were developed to perform the processing and analysis of this data. Section II summarizes the scientific results obtained from the analysis of data from these spacecraft. Appendix I is a bibliography of papers and meeting reports based on these experiments. Appendix II describes the form of the data submitted to the National Space Sciences Data Center under the terms of the contract.

Footnotes

- (1) IMP-4 was launched on 24 May, 1967, IMP-5 on 21 June, 1969.
- (2) IMP-4 re-entered the earth's atmosphere on 30 April, 1969, IMP-5 on 23 December, 1972.
- (3) On IMP-4 approx. 95% of all data was processed and analyzed. On IMP-5 approx. 95% of all data was processed and analyzed except for the following two periods which have not been received by Chicago as of the date of this report:
 - 1) Orbit 275 through Orbit 284
(Dec. 28, 1971 through Jan. 31, 1972)
 - 2) Orbit 368 through Orbit 381
(Nov. 8, 1972 through Dec. 23, 1972)

1. Processing and Analysis of IMP 4,5 Data

All data received by this Laboratory for the IMP-4 spacecraft, and all of the data received from the IMP-5 up to the date of this report have been processed (as defined below) and used for the various analyses required to obtain the reported scientific results. The yield of data from these spacecraft was very high; approximately 95% of all data telemetered by the spacecraft (some 17,000 hours for IMP-4, 30,000 hours for IMP-5) was processed by the Goddard Space Flight Center (GSFC), and was usable by us. As of the writing of this report, approximately 3 months of data from the IMP-5 has yet to be received here for processing⁽³⁾. We anticipate that this will be made available in the next 1-2 months.

The primary processing of the IMP 4/5 data required the design and implementation of eight major computer programs and several minor ones. Most of the processing was performed on an XDS (Xerox) 930 computer system, with one major processing step being performed (routinely) on an IBM 7094 computer. Figure 1 gives a general flow of the processing line used, while Figure 2 provides a more detailed operational flow diagram. In each case, a rectangle indicates a program (computer pass) and a circle a magnetic tape; other symbols are defined where used. Table 1 gives a brief description of each of the major programs used.

Four major types of problems have been encountered in processing this data. These were:

1. Pseudo-sequence count (PSC) discontinuities caused by GSFC processing errors (IMP-5 orbits 285, 286) or by perigee shadow shutdowns (12 orbits between 335 and 350). Each such discontinuity had to be corrected individually with considerable effort.
2. GSFC processing errors which caused major perturbations in the satellite clock (IMP-5 orbits 351-354). This was corrected by reprocessing at GSFC.
3. For both IMP-4 and IMP-5 there were blocks of time during which the sun location - and several related parameters - were incorrectly reported by GSFC. This problem was resolved by reprocessing the affected orbits through GSFC and the UC.
4. During orbits 269-284 of IMP-5, tracking was provided for only one day per orbit. A number of problems have been caused by this and, as of the time of this report, are not fully resolved by GSFC. As a result, we have not yet received orbits 275-284.

A larger number of minor problems have been detected and dealt with, of course. The cooperation and interest of the IMP Program Office and the Data Processing Branch staff at the GSFC has been vitally important in attacking these problems.

A considerable number of analysis programs - that is, programs which digest the processed forms described above and prepare displays necessary to the scientific analysis - have been written during the life of the IMP-4 and -5 experiments. Since these are highly specialized and intricate programs, they will not be described in detail here. These programs perform such functions as particle-type track summing, counting rate analysis, instrument dead-time calculators and spectra determination. Section II below reports the major scientific discoveries based on the use of these programs.

All of the IMP-4 data and approximately one year (June 1969 - July 1970) of the IMP-5 data has been submitted to the National Space Sciences Data Center (NSSDC), GSFC. Another year (through approximately July 1971) can be sent to the NSSDC as soon as tapes are provided by that Center. The data provided consists of a set of countin rate plots plus copies of the magnetic tapes "RAPT," "PHAEST," "RAST," and "ORPT" (see Figures 1, 2 and Appendix II for a description of these tapes) which, together with the documentation provided, comprises a complete set of reduced data from our experiments, suitable for use by other qualified investigators.

IMP- 4/5 ADP SYSTEM

All programs are on the XDS 930-except where noted.

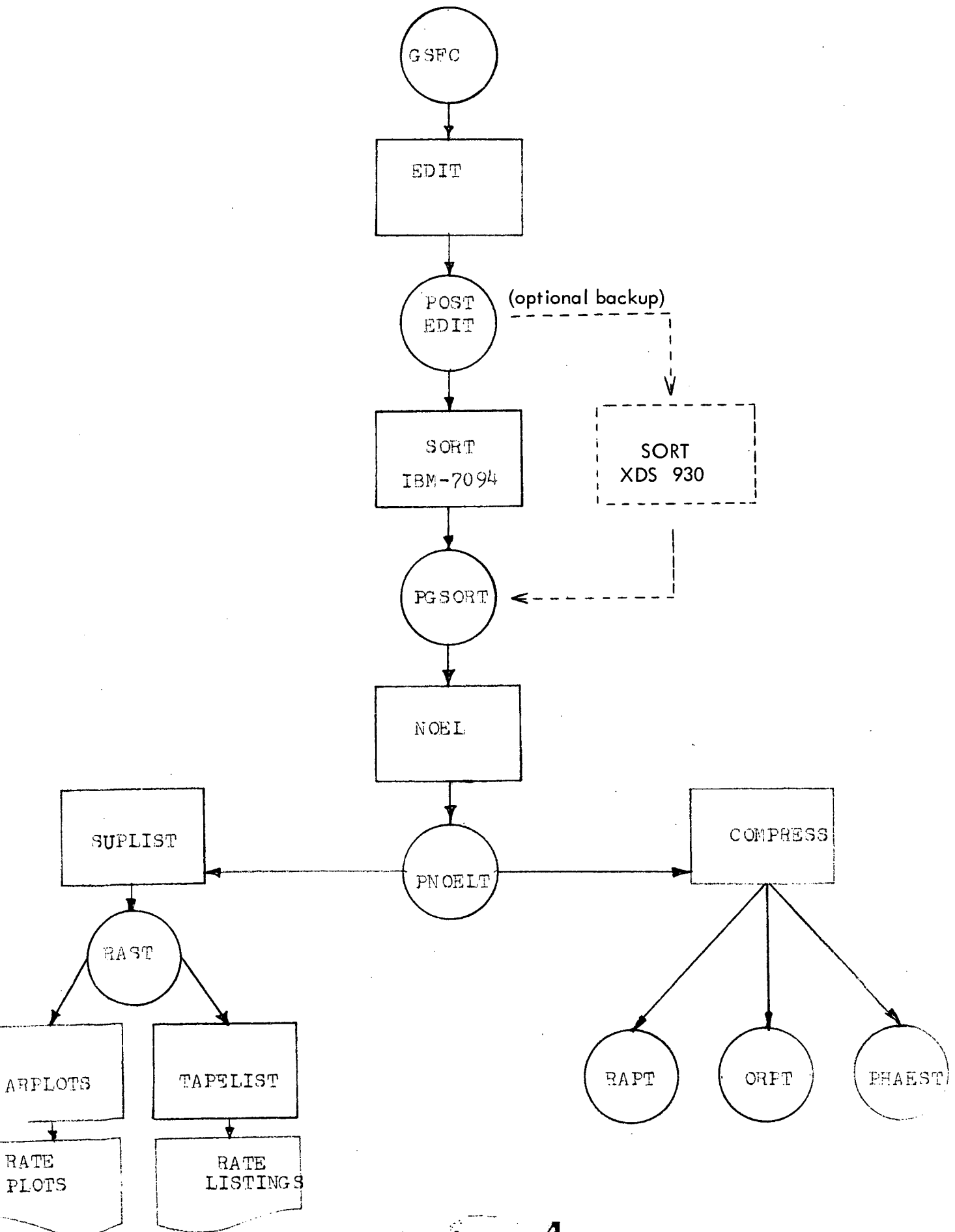


Figure 1 - 4

Figure 2
Detailed flow of the IMP-4/5
ADP System

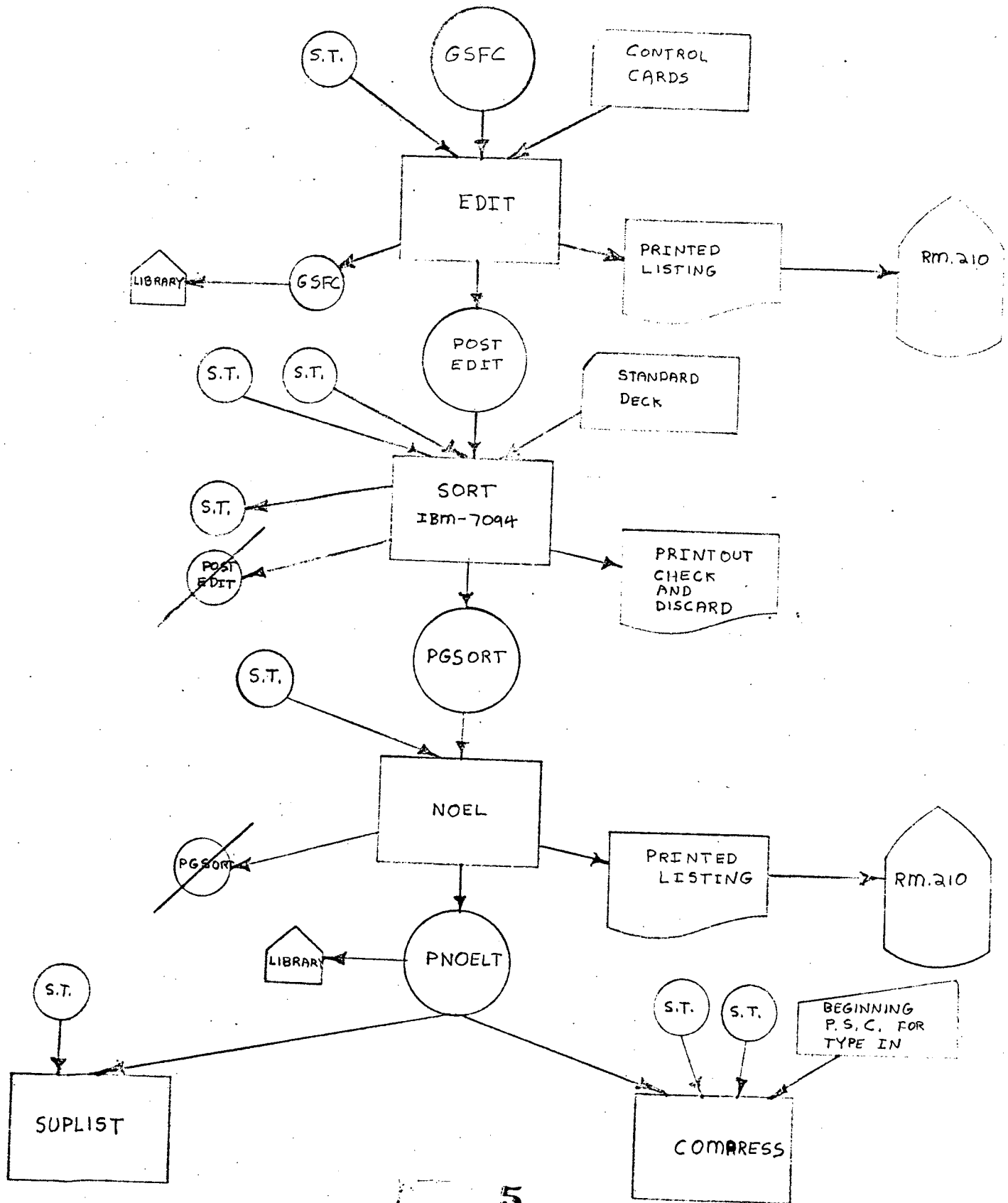


Figure 2 (page 2)

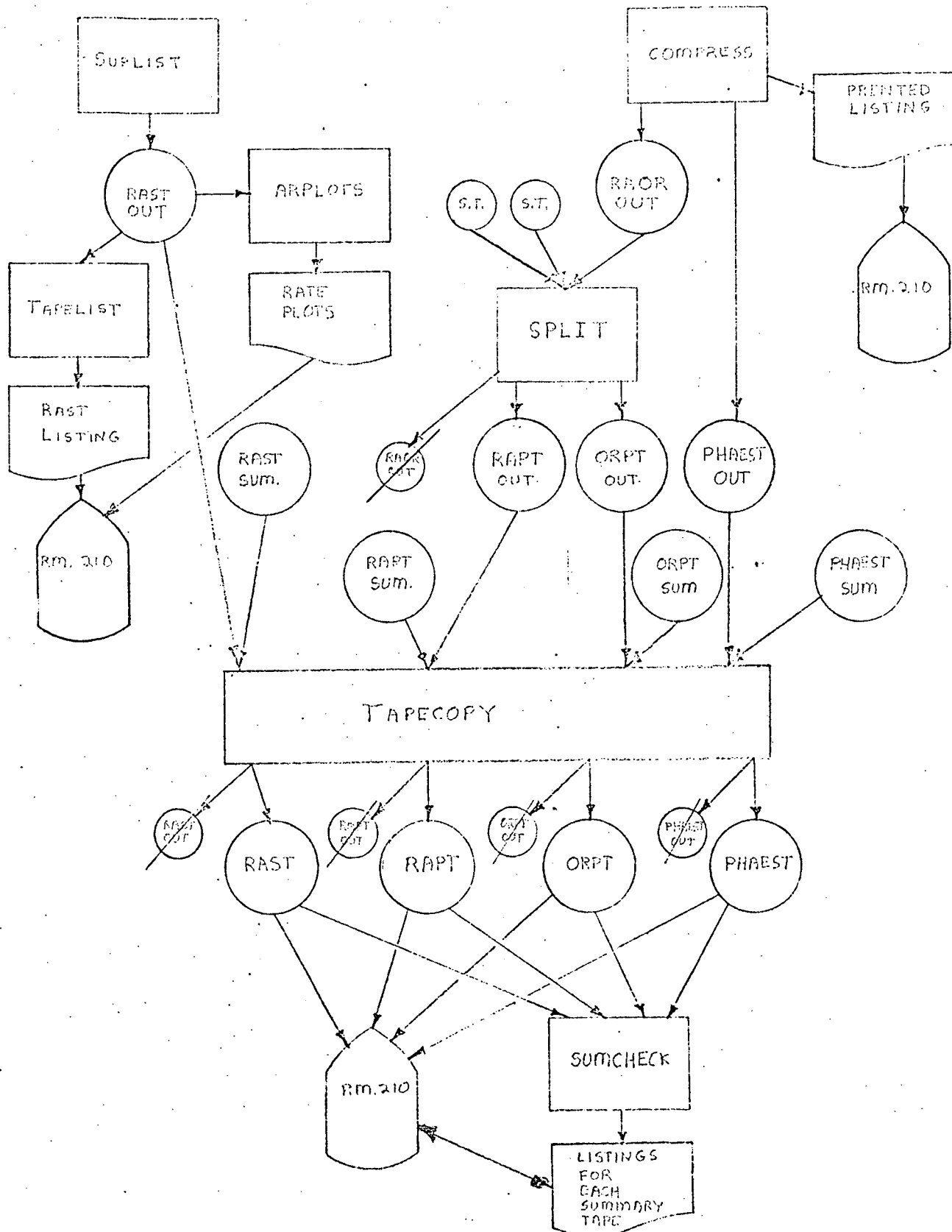


Table I

PROGRAM DESCRIPTIONS AND DATA-SET DEFINITIONS

Program or Data Set Name	Description/Definition
PRE-EDIT	Corrects the PSC and checks for errors in the satellite clock value. This routine was added to correct a GSFC processing problem which arose ~ July 1972.
EDIT	Reformats the pre-edit (or original data tape) to prepare it for the SORT.
SORT	Arranges the data in monotonically-increasing-time/PSC order.
NOEL	Eliminates overlap in the data using data quality as a selection criterion.
SUPLIST	Calculates 5-minute counting rate averages and prepares calibration-mode summaries.
COMPRESS/SPLIT	Separates rate, pulse height and orbit data into separate data bases.
ARPLOTS	Plots all rates for one orbit on a fixed -time-axis.
SUMCHECK	Validates the library-summary tapes.
TAPELIST	A system routine for selectively printing formatted data from tape.
TAPECOPY	A system routine for selectively copying a magnetic tape.
RAST	5-minute rate-average summary tape.
RAPT	Rate-accumulator summary tape; for short-time studies of rates.
PHAEST	Pulse height summary tape.
ORPT	Orbital parameter (position) tape.

II. Scientific Results of the University of Chicago IMP-4 and IMP-5 Satellite Experiments

The University of Chicago IMP-4 and IMP-5 experiments represented the first "2nd generation" charged particle telescopes built at this laboratory, and their post launch performance was characterized by very high resolution, low background measurements returned over the respective mission lifetimes. The scientific value of the IMP-4 and IMP-5 experiments is best indicated in the attached bibliography of scientific contributions to date by the principal investigator and his group using IMP-4 and IMP-5 data. As the bibliography⁽⁴⁾ shows, at present writing the measurements from these instruments have resulted in 6 Ph. D. theses from the University of Chicago Physics Department, the appearance of 9 journal articles and 25 papers presented at scientific conferences. Analysis of the IMP-4 and IMP-5 data is still actively underway in this laboratory, as indicated by the fact that at present writing 3 journal articles are in press, 3 articles are under consideration, and several additional articles are in preparation. In addition, 2 more students are now in the late stages of their Ph. D. thesis work using IMP-4 and IMP-5 data. Highlights of the contributions to cosmic ray research using the IMP-4 and IMP-5 data are outlined below.

A. GALACTIC COSMIC RAYS

The IMP-4 and IMP-5 experiments yielded the first high resolution measurements of the Galactic Cosmic Ray chemical composition over the range Hydrogen through the Iron group. These measurements showed, for example, that some cosmic ray nuclei of odd atomic number (Sodium and Aluminum) could not be absent in the cosmic ray sources as previously believed; since their large abundance could not be explained by spallation effects in the interstellar medium.

The IMP-5 experiment made the first measurement of Galactic Cosmic Ray spectra Helium through Oxygen over the broad energy range 10 - 1000 MeV per nucleon. This measurement allowed the first study of cosmic ray propagation at low energies which was not hampered by the uncertainties of using high energy normalizations from separate experiments.

The IMP-4 and IMP-5 experiments continued the study begun on IMP-3 of the rare isotopes of Galactic Cosmic Ray H^2 (Deuterium) and Helium-3. Those studies resulted in a refinement of models of galactic cosmic ray propagation and our knowledge of the source spectra.

The IMP-4 experiment has provided one of the only measurements of the ratio of Beryllium-7 to (Beryllium 9 + Beryllium 10). This measurements provides an indication of the age of the cosmic rays.

B. SOLAR MODULATION OF GALACTIC COSMIC RAYS

The IMP-4 and IMP-5 experiments have covered the onset of increasing modulation in the present solar cycle, the 1969-1970 solar maximum, and the very fast recovery of the 1971-72 period. Thus, a major part of a solar cycle was measured continuously with high resolution instruments for the first time. These IMP-4 and IMP-5 measurements provided the first experimental evidence for adiabatic deceleration in the interplanetary medium, and the first clear evidence for a phase-lag effect between low energy vs. high energy particle fluxes during the 1971-72 recovery from solar maximum modulation. Studies of the modulation of Helium vs. the heavier nuclei Carbon and Oxygen, established for the first time that the modulation mechanism is the same for particles of the same charge-to-mass ratio -- thus confirming one of the features of the diffusion, convection, adiabatic deceleration theory of the modulation process. In mid-1972, measurements from the IMP-5

experiment established the appearance of solar modulated galactic cosmic ray spectra with a feature never before observed: a Helium spectrum with a much flatter slope than the Proton spectrum, resulting in Helium flux levels greater than the Proton flux levels below ~ 35 MeV per nucleon.

The IMP-5 experiment has provided crucial baseline measurements for the University of Chicago Pioneer 10 experiments.

C. SOLAR FLARE ISOTOPES AND PARTICLE PROPAGATION

The IMP-4 and IMP-5 experiments were the first cosmic ray experiments to detect finite abundances of the rare isotope Helium-3 in solar flares, and these experiments have also significantly lowered the upper limits of the relative Deuterium abundance in solar flares. The measurements of these isotopes makes isotope analysis a new observational tool available for solar flare cosmic ray work.

Studies of solar flare particle propagation carried out with the IMP-4 experiment have included the study of "scatter-free" electrons at higher energies than previously reported, and a set of unique observations of solar flare proton propagation over wide ranges of solar azimuth using the University of Chicago IMP-4, Pioneer 6 and Pioneer 7 experiments.

The IMP-4 and IMP-5 experiments have provided crucial support for the University of Chicago OGO-5 (E-27) experiment, by determining Proton and Helium spectra (not covered by the OGO-5 experiment) during solar flare periods. This coverage from the IMPs was essential in the OGO-5 studies of heavy nuclei abundances in solar flares.

D. MAGNETOSPHERIC STUDIES

The IMP-4 experiment continued the neutral sheet and plasma sheet studies begun on the IMPs 1 and 3, in collaboration with the Goddard Space Flight Center Magnetometer experiment. These studies showed that with the onset of increasing solar activity in 1967-68,

energetic electrons continued to be present in these regions, although the distribution of events with respect to magnetic field data and other parameters was more complex than during periods near solar minimum.

The IMP-4 and IMP-5 experiments have provided essential monitoring of interplanetary particle fluxes in conjunction with studies of geomagnetically trapped Carbon, Nitrogen and Oxygen nuclei, performed with the University of Chicago OGO-5 experiment.

Appendix I.
Publications and Conference Proceedings
Based on Results from the University of Chicago
Experiment on the IMP 4 and 5 Satellites
(as of 31 December 1972)

Publications based on Results from the University of Chicago Experiment on the
IMP - 4 Satellite (as of 31 December 1972)

- K.C. Hsieh, "Study of Solar Modulation of Low Energy Cosmic Rays Using 1965 and 1967 Quiet Time Proton, He^3 and He^4 Differential Spectra at $E \lesssim 100$ MeV/nucleon, " *Astrophys. J.* 159, 61-67, 1970.*
- M. Garcia-Munoz and J. A. Simpson, "Galactic Abundances and Spectra of Cosmic Rays Measured on the IMP-4 Satellite I. Helium and Medium, and the Very Heavy Nuclei," 11th International Conference on Cosmic Rays, Budapest, 1969, *Acta Phys. Acad. Sci. Hung.*, 29, Suppl. 1, 317 (1970).
- M. Garcia-Munoz and J. A. Simpson, "Galactic Abundances and Spectra of Cosmic Rays Measured on the IMP-4 Satellite II. Li, Be, B and the Medium Nuclei," 11th International Conference on Cosmic Rays, Budapest, 1969, *Acta Phys. Acad. Sci. Hung.*, 29, Suppl. 1, 325, 1970.
- J. D. Sullivan, "Two Solar Flare Electron Components and their Relationship to the Proton Component," *J. Geophys. Res.* (in press).*
- K. C. Hsieh and J. A. Simpson, "The Isotopic Abundances and Energy Spectra of H^2 , He^3 and He^4 of Cosmic Ray Origin in the Energy Region $\sim 10 - 100$ MeV/Nucleon," *Ap. J. Letters* 158, L37 (1969)
- K. C. Hsieh and J. A. Simpson, "The Relative Abundances and Energy Spectra of He^3 and He^4 from Solar Flares," *Ap. J.* 162, L191 (1970).
- K. C. Hsieh and J. A. Simpson, "Galactic He^3 Above 10 MeV per Nucleon and the Solar Contributions of H and He," *Ap. J.* 162, L197 (1970).
- G. M. Comstock, K. C. Hsieh and J. A. Simpson, "Cosmic Ray Source and Local Interstellar Spectra Deduced from the H and He Isotopes," *Astrophysical Journal* 173, 691 (1972).
- R. B. McKibben, "Azimuthal Propagation of Low-Energy Solar Flare Protons as Observed from Spacecraft Very Widely Separated in Solar Azimuth," Ph. D. Thesis, University of Chicago, 1972; (used measurements from University of Chicago, IMP-4, Pioneer 6 and 7 experiments), *Jour. Geo. Res.*, 77, 3957, 1972.*
- R. B. McKibben, "The Interpretation of the Two Phase Decay of Low Energy (20 MeV) Solar Flare Protons Reported for Solar Flares in 1967-68," submitted to *J. Geophys. Res.**

* Ph. D. thesis, University of Chicago

Conference Proceedings based on Results from the University of Chicago Experiment
on the IMP-4 Satellite (as of 31 December 1972)

- J. A. Simpson, "Satellite Experiments on the Composition, Energy Spectra and Origin of the Cosmic Rays," invited paper presented at the December 1968 APS meeting, Bull. A.P.S., 13, 1397, 1968).
- J. D. Sullivan, "The Injection and Propagation of Solar Protons and Electrons Observed with the IMP-4 Satellite During 1967," presented at the December 1968 APS Meeting (Bull. A. P. S., 13, 1397, 1968).
- K. C. Hsieh, "Low Energy Galactic Hydrogen and Helium Nuclei Spectra Measured on the IMP-4 Satellite in 1967," presented at the December 1968 APS Meeting (Bull A.P.S., 13, 1410, 1968).
- M. Garcia-Munoz and J. A. Simpson, "Spectra of Low Energy Galactic He through Ne Nuclei," presented at the December 1968 APS Meeting, (Bull A.P.S., 13, 1410, 1968).
- R. B. McKibben, "Spectra of Cosmic Ray Protons and Alpha Particles Below 30 MeV per Nucleon," presented at the Midwest Cosmic Ray Conference, Baton Rouge, Louisiana, March 28-29, 1969.
- K.C. Hsieh, "1967 Galactic Proton, He^3 and He^4 Spectra Between 20 and 100 MeV/nucleon and Evidence of Adiabatic Deceleration in Interplanetary Space," presented at the Midwest Cosmic Ray Conference, Baton Rouge, Louisiana, March 28-29, 1969.
- K. C. Hsieh and J. A. Simpson, "Detection of the Isotope He^3 in Solar Flares," presented at the April 1970 APS Meeting, (Bull A.P.S., 15, 610, 1970.)
- G. M. Comstock, K. C. Hsieh and J. A. Simpson, "Production and Propagation of Low Energy Cosmic-Ray H^2 and He^3 " presented at the April 1970 APS Meeting (Bull A.P.S., 15, 618, 1970).
- M. Garcia-Munoz, "The Low Energy Galactic Cosmic Ray Oxygen and Carbon Spectra and their Modulation Parameters," presented at the April 1970 APS Meeting (Bull A.P.S., 15, 620, 1970).
- R. Cowsik, J. L. Mather, J. A. Simpson, J. D. Sullivan, D. H. Fairfield and N. F. Ness, "Energetic Electron Bursts in the Plasma and Neutral Sheets during 1964-68," presented at the National Fall Meeting of the A. G. U., San Francisco, California, December 7-10, 1970, Transactions of the A.G.U., 51, 815 (1970).

Conference Proceedings (IMP-4) cont.

- K. C. Hsieh, G. M. Comstock, and J. A. Simpson, "The Local Interstellar and Source Spectra of Cosmic Ray H and He Deduced from their Isotopes," Paper presented at the Spring APS Meeting (Bull. A.P.S., 16, 597, 1971).
- R. B. McKibben, "Observations of Solar Flare Proton Events Made from Very Widely Separated Spacecrafts," presented at the April 1972 meeting of the American Astronomical Society, University of Maryland (Bull. Amer. Astr. Soc., 4, 387, 1972).

Publications based on Results from the University of Chicago Experiment on
the IMP-5 Satellite

- B. G. Cartwright, M. Garcia-Munoz and J. A. Simpson, "Abundances of the Galactic Nuclei H through the Fe group from Satellite Measurements," presented at the 12th International Conference on Cosmic Rays, (Conference Papers, Vol. 1, 215).
- M. Garcia-Munoz, G. M. Mason, and J. A. Simpson, "Energy Dependence of Galactic He, L and M Nuclei from Satellite Measurements," presented at the 12th International Conference on Cosmic Rays, (Conference Papers, Vol. 1, 209).
- J. A. Simpson, "Galactic Sources and the Propagation of Cosmic Rays," Rapporteur paper presented at the 12th International Conference on Cosmic Rays, Hobart, Tasmania, 1971.
- K. C. Hsieh, G. M. Mason and J. A. Simpson, "Cosmic Ray H^2 from Satellite Measurements, 1965 to 1969," *Astrophysical Journal*, 166, 221, (1971).
- B. G. Cartwright, "The Origin of Fluorine, Sodium and Aluminum in the Galactic Cosmic Radiation," published in *Astrophysical Journal*, 169, 299, (1971).*
- G. M. Mason, "Interstellar Propagation of Galactic Cosmic Ray Nuclei $2 < Z < 8$ in the Energy Range 10-1000 MeV per Nucleon," published in *Astrophysical Journal*, 171, 139, (1972).*
- B. G. Cartwright, M. Garcia-Munoz and J. A. Simpson, "The Fluorine Abundance in the Galactic Cosmic Radiation," *Astrophys. Jour.* (in press for 1973).
- W. F. Dietrich, "The Differential Energy Spectra of Solar Flare H^1 , He^3 and He^4 ," *Astrophysical Journal* (in press for 1973).*
- M. Garcia-Munoz, G. M. Mason and J. A. Simpson, "A New Test for Solar Modulation Theory: the May-July 1972 Low Energy Galactic Cosmic Ray Proton and Helium Spectra," submitted to *Astrophysical Journal* (Letters) (1973).
- R. B. McKibben, J. J. O'Gallagher, J. A. Simpson and A. J. Tuzzolino, "The Heliocentric Radial Intensity Gradient of Galactic Cosmic Rays Between 1 and 2 Astronomical Units, (used measurements from University of Chicago IMP-5 experiment to provide a reference at Earth orbit for Pioneer-10 measurements), *Astrophysical Journal Letters* (in press for 1973).
- J. D. Anglin, W. F. Dietrich and J. A. Simpson, "Solar Flare Accelerated Isotopes of Hydrogen and Helium," invited talk presented at the Symposium on High Energy Phenomena on the Sun, Goddard Space Flight Center, Sept. 28-30, 1972. To be published by NASA, 1973.

* Ph.D. thesis

Conference Proceedings Based on Results from the University of Chicago Experiment
on the IMP-5 Satellite

- M. Garcia-Munoz and J. A. Simpson, "Solar Modulation of Low Energy Nuclei $1 \leq Z \leq 16$," Paper presented at the Spring Meeting of the American Physical Society, April 1971 (Bull A.P.S., 16, 565, 1971).
- G. M. Mason and J. A. Simpson, "Interstellar Propagation and Solar Modulation of Nuclei $2 \leq Z \leq 8$ in the Energy Range $10 - 10^3$ MeV/nucleon in 1969-70," Paper presented at the Spring APS meeting, 1971 (Bull A.P.S., 16, 597, 1971).
- B. G. Cartwright, M. Garcia-Munoz and J. A. Simpson, "The Source Abundances of He to Fe in the Galactic Cosmic Radiation Deduced from Abundances Observed on the IMP Satellites," presented at the joint meeting between the Division of Cosmic Physics, American Physical Society, and the High Energy Astrophysics Division of the American Astronomical Society, San Juan, Puerto Rico, December 1971.
- M. Garcia-Munoz, G. M. Mason and J. A. Simpson, "Solar Modulation of Differential Energy Spectra of Protons and Helium, 1965-1971," Paper presented at the Spring Meeting of the American Physical Society, April 1972 (Bull A.P.S. 17, 455, 1972.)
- J. A. Simpson, "Source Composition and Spectra of Galactic Cosmic Rays," Invited paper presented at the Spring Meeting of the American Physical Society, April, 1972, (Bull A.P.S., 17, 552, 1972).
- R. B. McKibben, J. J. O'Gallagher, J. A. Simpson and A. J. Tuzzolino, "The Integral and Differential Cosmic Ray Intensity Gradient from 1.0 to 1.4 Astronomical Units," post-deadline paper presented at the Annual Fall Meeting of the A.G.U., San Francisco, California, December 4-7, 1972.
- M. Garcia-Munoz, G. M. Mason and J. A. Simpson, "A New Test for Solar Modulation Theory: the May-July 1972 Low Energy Galactic Cosmic Ray Proton and Helium Spectra," post-deadline paper presented at the Annual Fall Meeting of the A.G.U., San Francisco, California, December 4-7, 1972.

Other Publications and Reports by the University of Chicago Making Major Use
of IMP 4/5 Data or Results

IMP-4 and IMP-5 Support of the University of Chicago OGO-5 "Hi-Z Low-E"
Experiment (experiment E-27).

University of Chicago IMP-4 and IMP-5 data has been to provide Helium
spectrum coverage and other correlation work with this experiment. Scien-
tific results from the OGO-5 E-27 experiment which used IMP -4 and
IMP-5 data are:

Journal Publications

- A. Mogro-Campero and J. A. Simpson, "Enrichment of Very Heavy Nuclei in the
Composition of Solar Accelerated Particles, " Astrophysical Journal Letters,
171, L5 (1972).
- A. Mogro-Campero and J. A. Simpson, "The Abundances of Solar Accelerated Nuclei
from Carbon and Iron," Ap. J. Let., 177, L37, (1972).
- A. Mogro-Campero, "Geomagnetically Trapped C, N, and O Nuclei, "
Journal of Geophysical Research, 77, 2799, 1972.*

Conference Proceedings

- A. Mogro-Campero and J. A. Simpson, "Enrichment of Very Heavy Nuclei in the
Composition of Solar Accelerated Particles," post-deadline paper presented
at the 12th International Conference on Cosmic Rays, Hobart, Tasmania, 1971.
- J. A. Simpson and A. Mogro-Campero, "Enrichment of Very Heavy Nuclei Accelerated
in Solar Flares," presented at the joint meeting between the Division of Cosmic
Physics, American Physical Society and the High Energy Astrophysics Division
of the American Astronomical Society, San Juan, Puerto Rico, 1971.
- A. Mogro-Campero and J. A. Simpson, "Overabundance of Very Heavy Nuclei Accel-
erated in Solar Flares," paper presented at the April meeting of the American
Astronomical Society 1972 Solar Physics Division Meeting, University of
Maryland.

Appendix 2:
Data Formats for Library Magnetic Tapes and Microfilm
from the University of Chicago Charged Particle Experiments
on the Satellites IMP-4 and IMP-5

Data Formats for Library Magnetic Tapes and Microfilm from
The University of Chicago Charged Particle Experiments on
the Satellites IMP-4 and IMP-5*

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CONTENTS

- I. Introduction
2. Instrumentation and Performance
 - 2.1 General Description
 - 2.2 Detector Telescopes
 - 2.2.1 IMP-4
 - 2.2.2 IMP-5
 - 2.3 Logic
 - 2.3.1 IMP-4
 - 2.3.2 IMP-5
 - 2.4 Telemetry Format
 - 2.5 Performance
 - 2.5.1 IMP-4
 - 2.5.2 IMP-5
3. Data Format of the Magnetic Tapes
 - 3.1 General Description
 - 3.2 RAte Packed Tapes
 - 3.3 RAte Summary Tapes
 - 3.4 Pulse Height Event Analysis Summary Tapes
 - 3.5 ORbit Parameter Tapes
4. Format for the Counting Rate Plots on Microfilm

1. Introduction

We are submitting to the NSSDC the final processed data obtained from the University of Chicago instruments on the eccentric polar orbiting satellites IMP-4 and IMP-5. IMP-4 data coverage is from the launch date of May 24, 1967 through April 29, 1969. IMP-5 data coverage is from the launch date of June 21, 1969, and continues until the present time (March, 1971). These data are presented on microfilm and on magnetic tape. On microfilm are time-intensity plots for the averaged counting rates with each plot corresponding to a Bartel's Solar Rotation. There are four categories of magnetic tape:

- 1) Averaged counting rates,
- 2) Raw accumulator readouts,
- 3) Pulse height analysis readouts, and
- 4) Orbit parameters.

This document describes the instruments, the formats of the data and the relationship between the data and the physical parameters the instruments were recording. A reference list of scientific publications by the University of Chicago group based on the IMP-4 and IMP-5 data is attached.

2. Instrumentation and Performance

The University of Chicago instruments on the satellites IMP-4 and IMP-5 are sufficiently similar that their characteristics can be described in parallel. The performance of the IMP-5 instrument will be reported when the data are submitted.

2.1 General Description

The University of Chicago instrument occupies one whole facet of the right octagonal cylinder of the IMP-4 (5) main body. Figures

1 and 2 show the location of the instruments and the orientation of the spacecrafts for IMP-4 and 5, respectively. The weight and power consumption of these instruments are listed in Table 1.

TABLE 1
Instrument Weight and Power

	IMP-4	IMP-5
WEIGHT (lb)	9.3	10.8
POWER (Watt)	2.1	2.3

2.2 Detector array

The instrument on IMP-4 has two telescopes, a composition telescope and an electron telescope, whereas the instrument on IMP-5 has only a composition telescope.

2.2.1 IMP-4:

2.2.1a Composition telescope:

A schematic of the composition telescope is shown in Figure

3. The anti-coincidence scintillation counter D6 and detector D1 define a geometrical factor of $1.6 \text{ cm}^2\text{-ster.}$

An aluminized mylar window protects the detectors from sunlight. The thickness of the telescope absorbers are tabulated in Table 2.

Composition Telescope Absorbers

Absorber name	IMP-4		IMP-5	
	THICKNESS (gm/cm ²)	MATERIAL	THICKNESS (gm/cm ²)	MATERIAL
Mylar Window	1.24×10^{-3}	Aluminized Mylar	1.24×10^{-3}	Aluminized Mylar
D ₁ Depletion depth	8.81×10^{-2}	Li-drifted Si	9.47×10^{-2}	Li-drifted Si
Dead layer	2.26×10^{-2}		7.6×10^{-3}	
D1-D2 shield	5.2×10^{-3}	Titanium	8.2×10^{-3}	Titanium
D ₂ Dead layer	3.19×10^{-2}	Li-drifted Si	1.33×10^{-2}	Li-drifted Si
Depletion depth	3.50×10^{-1}		3.62×10^{-1}	
D ₃ Depletion depth	1.93×10^{-1}	Li-drifted Si	1.97×10^{-1}	Li-drifted Si
Dead layer	3.98×10^{-2}		1.98×10^{-2}	
D4 Housing	2.21×10^{-2}	Magnesium	2.21×10^{-2}	Magnesium
D ₄	1.15×10^1	CsI (TI)	1.15×10^1	CsI (TI)
D4-D5 Housing	1.55×10^{-1}	Magnesium	1.77×10^{-1}	Magnesium
D ₅	6.48×10^{-1}	Plastic	5.72	CsI (TI)
D5-CK Housing	Not Applicable		2.56×10^{-1}	Magnesium
Cerenkov detector	Not Applicable		3.98	Sapphire (RCA-8664 PM tube)

TABLE 2

2.2.1b Electron telescope:

A schematic of the electron telescope is shown in Figure 3. This range total-energy telescope comprises an aluminized mylar window and a windowless Li-drifted silicon detector. The 44° acceptance cone and geometrical factor of $0.05 \text{ cm}^2 \text{ sr}$ are defined by an aluminum collimator which also serves as omni-directional shielding. The pertinent thicknesses are tabulated in Table 3.

TABLE 3

IMP-4 Electron Telescope Absorbers		
Absorber name	Thickness (gm/cm ²)	Material
Mylar window	1.24×10^{-3}	Aluminized Mylar
Detector Depletion depth Dead layer	0.3 0.03	Li-drifted Silicon
Omni-directional Shield	1.8	Aluminum

2.2.2 IMP-5

The IMP-5 composition telescope is shown schematically in Figure 4. The anti-coincidence scintillation counter D6 defines a geometrical factor of $1.6 \text{ cm}^2 \cdot \text{sr}$ for the 55° opening cone, and a geometrical factor of $1.1 \text{ cm}^2 \cdot \text{sr}$ for the 36° opening cone. An aluminized mylar window protects the detectors from sunlight. Absorber thicknesses are shown in Table 2.

2.3 Logic

Logic diagrams of the two instruments are shown in Figures 5 and 6 respectively. The logic of each instrument has two modes (c.f. tables 9 and 10):

- 1) Normal mode, and
- 2) Calibrate mode.

2.3.1 IMP-4:

2.3.1a Composition Telescope

Normal Mode. Signals from all the detectors are utilized to give information concerning the flux of cosmic ray particles. This information is derived from six counting rates and three pulse-height analysis (PHA) readings from the composition telescope and two counting rates from the electron telescope. The eight counting rates and their readout frequencies are listed in Table 4. $D1\overline{D2D6}$ is pre-scaled by 8 when the counting rate $\geq 22 \text{ KHz}$; $D1\overline{D2D3D6}$ is pre-scaled by 128 when the counting rate $\geq 1.5 \text{ KHz}$.

TABLE 4
IMP-4 Counting Rates

Counting Rate	Readout Frequency
$D1_H \overline{D2D6}$	Four times per sequence*
$D1_H \overline{D2D3D6}$	Twice per sequence
$D1_H D2D3D4 \overline{D5_L D6}$	"
$D1_L D2D3D4 \overline{D5_L D6}$	"
D5 (Analog count rate meter)	Once per sequence, 128 consecutive sequences every 1024 sequences
D6 (Analog count rate meter)	Once per sequence, 896 consecutive sequences every 1024 sequences
E1 (cf sec. 2.3.1b)	Once per sequence
E2 (cf sec. 2.3.1b)	"
*c.f. Sec. 2.4 for sequence time	
Note: Settings of $D1_L$, $D1_H$, $D5_L$ and $D5_H$ are explained in 2.5.1a	

During each frame (cf.sec. 2.4), one incident particle may be pulse-height analyzed and recorded together with its angular sector (AS) and range identification (ID) information. The three 256-channel pulse-height analyzers are assigned to detectors D1, D2 and D4 respectively. The angular sector information comes from the Optical Aspect package on the spacecraft and signifies an octant in a plane* perpendicular to the spin axis in which the PHA occurred (see Figure 7). The range identification indicates the number of detectors the PHA event has triggered, i.e. a particle that penetrated D1 and D2 and stopped in D3 would be an ID = 3

* Essentially the ecliptic. 27

event and correspondingly the PHA reading from D4 should be zero.

The definition of the ID's and the corresponding proton and electron energies are given in Table 5.

TABLE 5
IMP-4 Composition Telescope Energy Ranges

ID	Definition	Proton Energy (MeV)	Electron Energy (MeV)*
0	Calibrate mode	--	--
1	$D1_H \overline{D2D6}$	$0.78 - 9.55 (+0.07)$	$0.17 \sim 1.0$
2	$D1_H D2 \overline{D3D6}$	$9.6 - 18.8 (+0.2)$	$0.75 \sim 1.6$
3	$D1_H D2D3 \overline{D4D6}$	$18.8 - 29.5 (+0.7)$	$1.4 \sim 3.0$
4	$D1_H D2D3D4 \overline{D5D6}$	$29.5 - 94.2 (+1.5)$	$14 \sim 45$
5	$D1_L D2D3D4D5_L \overline{D6}$	$> 170 \pm 10$	$\gtrsim 40$
6	$D1_L D2D3D4D5_L D5_H \overline{D6}$	$94 - 170$	--
7	Not defined	--	--

* electron energies are approximate because of range straggling.

Not all ID's have an equal chance of being read out. When the stored PHA event is either an ID = 1 ($D1_H \overline{D2D6}$) or ID = 5 or 6 ($D1_L D2D3D4D5_L \overline{D6}$), then prior to readout another PHA event may replace it. However, when the stored event is either an ID = 2 ($D1_H D2 \overline{D3D6}$), ID = 3 ($D1_H D2D3 \overline{D4D6}$) or ID = 4 ($D1_H D2D3D4 \overline{D5D6}$), the storage will be locked and no event may replace this event prior to readout. In other words, ID = 2, 3 and 4 type of events have priority over ID = 1, 5 and 6 events for storage and readout.

Calibrate Mode. When the instrument is in calibrate mode, the ID

is set to zero. For every 8192 sequences, there are 128 consecutive sequences of calibrate mode, during which: (1) all coincidence requirements for the counting rates are removed so that individual detector counting rates may be monitored, and (2) in the final three readouts of a sequence each of the three analyzers are calibrated with pulses of different fixed amplitudes to monitor possible gain-shifts in the system.

2.3.1b Electron telescope

Normal Mode. The signal from the detector is analyzed with a two-channel pulse height analyzer and the counting rate of each channel is telemetered (cf. sec 2.4). Table 6 summarizes energy ranges of this telescope and Table 4 the readout frequency.

TABLE 6

IMP-4 Electron Telescope Energy Ranges

Designation	Electron Energy Interval (keV)	Proton* Energy Interval (keV)
E1	85 - 135	$\sim 750^+$
E2	160 - 370	$\sim 850^+$

* For the detection of protons with energies > 32 MeV, which penetrate the Al shielding, the effective omni-directional geometrical factor is $0.2 \text{ cm}^2 \text{ sr}$.

+ Collimated protons are counted only in a narrow energy band width (~ 40 keV) just above the window penetration energy.

Calibrate Mode. During calibrate mode the electron telescope is unaffected except that one pulse (count) is added to the E1 channel for the last three readouts of each calibrate sequence.

2.3.2 IMP-5:

Normal Mode. Signals from all the detectors are utilized to give information concerning the flux of cosmic ray particles. This information is derived from six counting rates and three pulse-height analysis (PHA) readings. The counting rates and their readout frequencies are listed in Table 7.

TABLE 7
IMP-5 Counting Rates

Counting Rate	Readout Frequency [‡]
$D1\overline{D2D6}$	Four times per sequence*
$D1D2\overline{D3D6}$	Twice per sequence
$D1D2\overline{D3D6}$ (prescaled by 128)	Once per sequence
$D1D2D3D4\overline{D5_LD6}$	Twice per sequence
$D2D3D4D5_L\overline{CKD6}$	Once per sequence
$D2D3D4D5_LCK\overline{D6}$	Twice per sequence
D5 (Analog count rate meter)	Once per sequence, 128 consecutive sequences every 1024 sequences
D6 (Analog count rate meter)	Once per sequence, 896 consecutive sequences every 1024 sequences
[‡] Nominal accumulation time for all but analog rates is 4.80 seconds immediately preceding readout. * IMP-5 Sequence time will be included in post launch performance report. Note: Settings of $D5_L$ and $D5_H$ are explained in Sec. 2.5.2	

The rate $D1\overline{D2D6}$ is prescaled by 8 when this counting rate is ≥ 22 KHz. Accumulation periods when this prescaling is in effect are indicated by setting RR1 (cf. Table 10) to 1.

The rate $D1D2\overline{D3D6}$ collected in accumulator 7b is prescaled by 128 whenever this rate is greater than ≥ 1.3 KHz. As there is no separate indication of whether the $D1D2\overline{D3D6}$ rate is prescaled, this must be determined by comparing this rate with the permanently prescaled $D1D2\overline{D3D6}$ rate, which

collects in accumulator 7a. The prescaling on the $\overline{D1D2D3D6}$ (7a) rate is such that it collects the 1st count, then the 129th count, etc.

During the 4.8 seconds of each accumulation interval, one PHA event may be registered together with its angular sector (AS) and range identification (ID) information. The PHA comes from three pulse height analyzers: PHA1, 256 channels, assigned to D1 for ID = 0 to 5, and assigned to CK for ID = 6 and 7; PHA2, 512 channels, assigned to D2; PHA4, 256 channels, assigned to D4. The angular sector information comes from the Optical Aspect Sensor on the spacecraft and signifies an octant in the ecliptic^{*} plane in (cf. figure 7). which the PHA occurred/ The range identification indicates the number of detectors the PHA event has triggered; i.e. a particle that penetrated D1 and D2 and stopped in D3 would be an ID = 3 event, and correspondingly the PHA reading from D4 should be zero. The definition of the IDs and the corresponding proton energies are given in Table 8.

* Actually in a plane perpendicular to the spacecraft spin axis which is approximately normal to the ecliptic plane.

TABLE 8
IMP-5 Energy Ranges

ID	Definition	Proton Energy (MeV)
0*	Calibrate mode, analyze D1, D2, D4	
1	D1 D2 $\overline{D6}$	0.78 - 8.45 (± 0.25)
2	D1 D2 $\overline{D3 D6}$	8.45 - 18.7 (± 0.3)
3	D1 D2 D3 $\overline{D4 D6}$	18.7 - 30.9 (± 2)
4	D1 D2 D3 D4 $\overline{D5_L D6}$	30.9 - 94.8 (± 1)
5	D1 D2 D3 D4 D5_L $\overline{CK D6}$	94.8 - 119 ⁺
6	D1 D2 D3 D4 D5_L $\overline{CK D6}$	> 119
7	Calibrate mode, analyze CK, D2, D4	
⁺ Since some particle trajectories pass through the D5, but do not hit CK (see Figure 4), ID5 events include a percentage of particles with energies > 119 MeV. *Also see 2.5.2a.		

Not all events have an equal chance of being readout. If an event satisfies the condition $D1 D2 \overline{D6} (\overline{D5_L} + D5_H)$, the analysis gates are locked (high priority event) and no other event will be analyzed during the accumulation period in progress. If this priority condition is not met (low priority event), each succeeding event will be analyzed until the end of the accumulation period. Thus, ID = 1 events are low priority; ID = 2, 3 or 4 events are high priority; ID = 5 or 6 events may be high or low priority (cf. sec.2.5.2a).

Calibrate Mode. When the instrument is in calibrate mode, the

ID is 0 or 7. For every 8192 sequences, there are 128 consecutive sequences of calibrate mode, during which:

- (1) coincidence requirements for the counting rates are modified as indicated in Table 10, and
- (2) in the latter three readouts of a sequence each of the three analyzers are calibrated with pulses of different fixed amplitudes to monitor possible gain-shifts in the system.

2.4 Telemetry Format

The IMP-4 and IMP-5 spacecrafts transmit one complete set of readouts every 20.48 seconds[‡], and this is called one SEQUENCE. Every SEQUENCE is divided into 16 FRAMES (0 through 15) and each FRAME into 16 CHANNELS (0 through 15). The main portion of the University of Chicago output is contained in CHANNELS 8 through 15 of FRAMES 2, 6, 10, and 14 of each SEQUENCE. The analog ratemeter that monitors the D5 and D6 counting rates alternatively has its output in CHANNEL 15 of FRAME 4 of every SEQUENCE while the temperature of the University of Chicago instrument is in CHANNEL 14 of FRAME 12 of every even numbered SEQUENCE. The voltage delivered to the University of Chicago experiment is read out in CHANNEL 11 of FRAME 4

[‡] This is the nominal value. The University of Chicago uses a value of 20.45439 seconds for IMP-4.

of every SEQUENCE. Tables 9 and 10 show the telemetry format of the University of Chicago experiment on IMP-4 and IMP-5 respectively.

The rate accumulators are open only for 60 channels: from the beginning of channel 12 to the end of channel 7 four frames later; also the PHA registers are open for 59 channels: from the beginning of channel 0 to the end of channel 10 three frames later.

Each SEQUENCE telemetered during the life of the satellite is assigned a unique number called the pseudo-sequence count (PSC).

The PSC is the same as the Satellite Clock immediately after launch, and the PSC is increased by 1 for each sequence thereafter. The Decommutation program run at the / Goddard Space Flight Center handles the PSC assignment, including corrections for data gaps, recycling the satellite clock, and any abnormalities that might occur to the satellite clock. Thus the PSC is a linearly increasing clock which measures time in units of readout sequences. The PSC is used as the basic time monitor for all the University of Chicago data described in this document.

2.5 Performance

2.5.1 IMP-4

2.5.1a Pre-launch

The instruments have been carefully calibrated prior to launch on its electronic characteristics and its response to protons and electrons. Table 11 shows the thresholds of the detectors and Table 12 tabulates the pulser calibration of the PHA's.

TABLE 9

THE UNIVERSITY OF CHICAGO IMP-4 TELEMETRY FORMAT

Channel	8	9	10	11	12	13	14	15
Number of bits	10	10	12		3	3	8	8
Accumulator	7a (S-T)	7b (S-T)	7c (S-T)		Chicago Digital Scan			
F R A M E	2	$D_{1L} D_2 D_3 D_4 D_5$ \overline{D}_6 cal: D_{5L}	$D_{1H} \overline{D}_2 \overline{D}_6$ cal: D_{1H} prescale: 1/8		ID RR AS	D_1 PHA	D_2 PHA	D_4 PHA
	6	$D_{1H} D_2 D_3 D_4$ $\overline{D}_{5L} \overline{D}_6$ cal: D_4	$D_{1H} D_2 \overline{D}_3 D_6$ prescale: 1/128 cal: D_3	"	" " "	"	"	"
	10	E-1 prescale: 2	$D_{1L} D_2 D_3 D_4$ $D_{5L} \overline{D}_6$ cal: D_{5L}	"	" " "	"	"	"
	14	$D_{1H} D_2 D_3 D_4$ $\overline{D}_{5L} \overline{D}_6$ cal: D_4	$D_{1H} D_2 \overline{D}_3 \overline{D}_6$ cal: D_2 prescale: 1/128	"	" " "	"	"	"

- Analog Outputs:
1. D_{5L}/D_6 in PP10 (once per sequence)
 \overline{D}_{5L} During sequences 0 through $895 + 1024n$ ($n \geq 0$)
 D_6 During sequences 896 through $1023 + 1024n$
 2. Telescope temp. in PP19 (once per two sequences)

Calibrate: ID = 0
 Sequence normally within 7936 through $8063 + 8192n$ ($n \geq 0$)

Prescaling: None except if: 1. $RR1 = 1$, $D_{1H} \overline{D}_2 \overline{D}_6$ and D_{1H} cal. prescaled by factor of 8
 2. $RR2 = 1$, $D_{1H} D_2 \overline{D}_3 \overline{D}_6$ and D_2 cal. prescaled by factor of 128

TABLE 10

THE UNIVERSITY OF CHICAGO IMP-5 TELEMETRY FORMAT

Channel	8	9	10	11	12	13	14	15
Bit Accumulator	0 1 2 3 4 5 6 7 7a (S-T)	0 1 2 3 4 5 6 7 7b (S-T)	0 1 2 3 4 5 6 7 7c (S-T)	0 1 2 3 4 5 6 7	0 1 2 3 4 5 6 7 Chicago Digital Scan	0 1 2 3 4 5 6 7	0 1 2 3 4 5 6 7	0 1 2 3 4 5 6 7
F	$\overline{D_2} \overline{D_3} \overline{D_4} \overline{D_5} \overline{L} \overline{CK}$ $\overline{D_6}$	$\overline{D_2} \overline{D_3} \overline{D_4} \overline{D_5} \overline{L} \overline{CK}$ $\overline{D_6}$ Cal: C_K	$\overline{D_1} \overline{D_2} \overline{D_6}$ Cal: D_1 Prescale: 1 if $RR1 = 0$ 8 if $RR1 = 1$	ID	PHA 1 Cal: Background	PHA 2 (D2) Bits 0-7 Cal: Background	PHA 4 (D4) Cal: Background	
R	$\overline{D_1} \overline{D_2} \overline{D_3} \overline{D_4} \overline{D_5} \overline{L}$ $\overline{D_6}$ Cal: $D_4 \overline{D_5} \overline{L}$	$\overline{D_1} \overline{D_2} \overline{D_3} \overline{D_6}$ Prescale: 1/128 Cal: D_3	"	"	PHA 1 Cal: Onboard pulser	PHA 2 (D2) Cal: Onboard pulser	PHA 4 (D4) Cal: Onboard pulser	
A	$\overline{D_1} \overline{D_2} \overline{D_3} \overline{D_6}$ Cal: D_2 Prescale: 128	$\overline{D_2} \overline{D_3} \overline{D_4} \overline{D_5} \overline{L} \overline{CK}$ $\overline{D_6}$ Cal: C_K	"	"	"	"	"	
M	$\overline{D_1} \overline{D_2} \overline{D_3} \overline{D_4} \overline{D_5} \overline{L}$ $\overline{D_6}$ Cal: $D_4 \overline{D_5} \overline{L}$	$\overline{D_1} \overline{D_2} \overline{D_3} \overline{D_6}$ Cal: D_2 Prescale 1/128	"	"	"	"	"	
E								

Analog outputs: 1) $\overline{D_5} \overline{L} / \overline{D_6}$ in PP12 (once per sequence); $\overline{D_6}$ during sequences 0 through $895 + 1024n$ ($n \geq 0$); $\overline{D_5} \overline{L}$ during sequences 896 through $1023 + 1024n$.
2) Telescope temperature in PP 19 (once per 2 sequences)

Calibrate: ID = 0 and 7 in alternate sequences, during sequences from 7936 through $8063 + 8192n$ ($n \geq 0$)
PHA 1 - C_K if ID = 6 or 7; D_1 if ID = 0, 1, 2, 3, 4, or 5.

Prescale of $\overline{D_1} \overline{D_2} \overline{D_3} \overline{D_6}$ in 7b (6, 14) and $\overline{D_2}$ cal in 7b (14) is 1 unless at high rates (≈ 2 KC), 7a (10) \approx 7b (6, 14), in which case prescale is 128.

TABLE 11
IMP-4 Detector Thresholds

D1 _L	D1 _H	D2	D3	D4	D5 _L	D5 _H	D6
(mV)	(mV)	(mV)	(mV)	(mV)	(V)	(V)	(mV)
0.34	0.65	1.20	0.81	0.37	.196	1.56	14.1
<p>Threshold is defined as one-half of full triggering.</p> <p>D1_L and D5_L are set to include minimum ionizing protons; D5_H is set to exclude lower than minimum ionizing He⁴; and D1_H is set just above minimum ionizing protons.</p>							

Calibrations of the PHA by using a beam of accelerated protons between 15 and 200 MeV and cosmic ray muons give energy to pulse-height conversion factors which are compared with those obtained after launch in Table 13.

2.5.1b Post-launch

The satellite IMP-4 was launched on 24 May 1967 and terminated its life on 3 May 1969. During its mission the University of Chicago instrument went through temperature variations (seasonal and secular) as shown in Figure 8 which did not exceed the thermal specifications of the instrument, except for the severe temperature drops, not shown on the curve, during the two ~ 7-hour shadows.

Figures 9a, b and c show the shifts in the D1, D2 and D4 PHA systems, respectively, as indicated by the in-flight pulser calibrations. The shifts of the analyzers also can be checked for any part of the mission by

TABLE 12. IMP-4 PHA Calibration

Pulser Input (mV)	Channel Numbers		D ₄	Pulser Input (mV)	D ₁	Channel Number D ₂	D ₄
	D ₁	D ₂	Threshold at 0.39 mV				
0.4			1.4	50.0	75.3	22.0	167.8
0.5			2.3	60.0	90.1	26.1	171.7
0.6			3.3	70.0	105.3	30.8	176.0
0.7	Threshold at 0.71 mV		3.8	80.0	120.8	35.0	180.2
0.8	2.7		3.9	90.0	128.6	38.8	184.0
0.9	2.9		4.6	100.0 mV	130.9	43.0	188.0
1.0	3.0	Threshold at 1.27 mV	5.4	0.15V	139.0	63.4	208.3
1.5	3.5	2.2	8.2	0.20	146.4	84.0	228.5
2.0	4.1	2.5	11.4	0.25	154.2	105.0	245.8
3.0	6.0	3.0	18.0	0.30	161.2	126.0	249.0
4.0	7.0	3.4	24.8	0.35	169.2	140.4	250.0
5.0	9.0	4.0	30.9	0.40	176.9	143.1	Limit
6.0	10.0	4.3	37.3	0.50	191.8	148.2	
7.0	11.9	5.0	44.4	0.60	207.0	153.4	
8.0	13.0	5.0	50.7	0.70	222.0	158.5	
9.0	14.9	6.0	57.3	0.75	229.5	161.2	
10.0	16.0	6.0	64.1	0.80	237.0	163.5	
12.0	19.0	7.0	76.8	0.90	249.0	168.2	
14.0	22.0	8.0	90.2	1.00	252.0	173.5	
16.0	25.0	8.5	102.4	1.50	253.0	191.2	
18.0	28.0	9.0	116.3	2.00	Limit	222.5	
20.0	31.0	10.0	129.4	2.25		234.5	
30.0	45.7	14.0	159.0	2.50		246.0	
40.0	60.1	18.1	163.3	3.00 V		252.0	
						Limit	

noting the positions of the proton and He^4 tracks. Using the latter method, the energy to pulse-height conversion factors from orbits 1-36 are shown in Table 13.

TABLE 13
IMP-4 Conversion Factors

PHA	Pre-launch		Orbits 1 thru 36		Units
	Muon	Proton	Proton	He^4	
D1	-	191 ± 18	193 ± 16	200 ± 16	keV/mV
D2	-	214 ± 18	204 ± 16	201 ± 16	keV/mV
D4	20.8 ± 2.9	25.4 ± 2.2	22.0 ± 2.0	20.8 ± 2.0	MeV/mV

The PHA system as a whole was quite steady throughout the mission, except the D3 detector malfunctioning disturbed the range ID and the deterioration of the D4 system caused an ID = 4 analysis difficulty toward the end of 1967. A list of historical events in the life of the instrument is shown in Table 14.

TABLE 14
IMP-4 Satellite History

IMP-4	1967-51-A	Explorer 34
Launch: WTR May 24, 1967 (Day 144)		
First Quick-look data received:		June 1, 1967 (Day 152)
First Production data received:		Aug. 2, 1967 (Day 214)
Last Production Data received:		Oct. 7, 1969 (Day 280)
<u>Day</u>	<u>Orbit</u>	<u>Description</u>
May 30, 1967 (Day 150)	2	E2 rate fails, returns all zeros.
Sept. 21, 1967 (Day 264)	28	E1 rate goes noisy.
Nov. 16, 1967 (Day 320)	41	D3 begins to go noisy*
Dec. 11, 1967 (Day 345)	47	D4 calibrate peak begins to spread.
Jan. 15, 1968 (Day 15)	55	D4 proton track begins to degrade.
Mar. 5, 1968 (Day 65)	67	Begin getting 2 peaks in D3 calibrate.
Mar. 7, 1968 (Day 67)	67	First Shadow, ~ 7 hours long, electron telescope dies.
Sept. 17, 1968 (Day 261)	112	D3 noisy at $\sim 7 \times 10^4$ c/sec from here to end of mission.
Oct. 16, 1968 (Day 290)	119	ID2 proton track shifted one channel.
March 4, 1969 (Day 63)	151	Second shadow, ~ 7 hours long; there is no valid optical aspect data after this.
May 3, 1969 (Day 123)	164	Last day of data.

* Fairly quiet from 110'68 to 149'68 (orbits 77-87). Then noisy to end.

2.5.2 IMP-5:

2.5.2a Pre-launch

The instrument has been carefully calibrated prior to launch on its electronic characteristics and its response to protons and electrons. Table 15 shows the thresholds of the detectors and Table 16 tabulates the pulser calibration of the PHA's.

TABLE 15

IMP-5 Detector Thresholds

D1	D2	D3	D4	D5 _L	D5 _H	CK	D6
(mV)	(mV)	(mV)	(mV)	(mV)	(mV)	(mV)	(mV)
0.685	1.35	0.640	0.275	0.105	1.39	2.08	19.6
Threshold is defined as one-half of full triggering. Thresholds are measured at room temperature.							

All detector thresholds are set to include minimum ionizing protons, except:

D1: includes only about 1/3 of minimum ionizing protons. If a particle fails to trigger D1 but does trigger CK, it is analyzed as a low priority event with $ID = 0$. In this case, PHA1 is assigned to CK.

CK: does not trigger on most protons moving backwards through the telescope. If such events trigger D1, they will be analyzed as $ID = 5$ events.

D5_H threshold: This threshold determines whether or not an event of $ID = 5$ or 6 will be high or low priority. Particles that do not pass through one of the D5 photodiodes must deposit ~ 63 MeV in the D5 CsI crystal to trigger D5_H. If a particle passes through a photodiode, it will always trigger D5_H if its charge is ≥ 2 . Summarizing, for $ID = 5$ or 6,

- 1) $Z = 1$ all particles have low priority.
- 2) $Z = 2$
 - a) Forward moving particles of incident energy < 220 MeV/nucleon are high priority.
 - b) Forward moving particles (≥ 220 MeV/nucleon) and backward moving particles (all energies) have high priority $34.5 \pm 2\%$ of the time, since they hit a photodiode (this applies to 36° cone only).
- 3) $Z \geq 3$ all particles have high priority.

TABLE 16. IMP-5 PHA Calibration

Pulser Input (mV)	Channel Numbers				Pulser Input (mV)	Channel Numbers			
	D1	D2	D4	CK		D1	D2	D4	CK
			Threshold at .27 mV						
0.3			1.9		60.0	100.0	57.0	172.5	42
0.4			2.3		70.0	116.0	63.0	177	48
0.5			2.7		80.0	130.0	75.5	181.5	54
0.6	Threshold at 0.69 mV		3.1		90.0	133.0	84.0	186	62
0.7	3.2		3.5		100.0	134.0	94.0	190.5	68
0.8	3.4		3.9		150.0	142.0	140.0	214	102
0.9	3.6		4.3		170.0	144.5	159	223	111
1.0	3.7	Threshold at 1.35 mV	4.7		180.0	146.0	168	228	113
1.5	4.5	2.5	6.6		190.0	147.5	177	232.5	116
2.0	5.3	3.0	8.6	Threshold at 2.1 mV	200.0	149.0	187	237	119
3.0	6.9	3.9	12.5	4.9	280.0	160.5	260	248	141
4.0	8.5	4.9	16.5	5.6	300.0	163.5	268	250	147
5.0	10.1	5.8	20.5	6.2	320.0	166.5	273	Limit	152
6.0	11.7	6.8	25.5	6.8	340.0	169.0	276		157
7.0	13.3	7.7	30.0	7.5	400.0	178.0	282		173
8.0	14.9	8.7	34.0	8.1	500.0	192.5	292		201
9.0	16.4	9.6	38.5	8.7	600.0	207.0	302		231
10.0	18.0	10.5	42.0	9.3	700.0	221.5	312		243
12.0	21.0	12.3	50.0	10.6	800.0	237	321		244
14.0	24.5	14.2	52.0	11.9	900.0	245	331		Limit
16.0	27.0	16.1	66.0	13.1	1.0 V	Limit	341		
18.0	31.0	18.0	75.0	14.5	1.5 V		388		
20.0	34.5	19.8	82.5	15.7	2.0 V		435		
30.0	51.0	29.5	124.0	22	2.5 V		482		
40.0	67.0	39.0	162	28	3.0 V		500		
50.0	84.0	47.5	168	35	3.5 V		Limit		

2.5.2b Post-launch

An appendix to this document, which will be submitted at a later date, will contain the post launch performance of the IMP-5 instrument, as well as a comparison of pre-launch and post-launch response to protons and electrons.

3. Data Format of the Magnetic Tapes

3.1 General Description

All magnetic tapes were generated on an XDS 930 computer at a density of 800 BPI on seven track tape. Each tape is labelled with an appropriate mnemonic of the type of data recorded on it: 'RAST' for RAte Summary Tape, 'RAPT' for RAte Packed Tape, 'PHAEST' for Pulse Height Analysis Event Summary Tape, and 'ORPT' for ORbit Parameter Tape. In addition, a number representing the sequential order of the tape in its respective category appears on the tape label.

An end of file mark terminates each orbit and a double end of file mark terminates the last orbit of each tape. An orbit contains a variable number of physical records. 'ORPT', 'PHAEST', and 'RAPT' are written in binary, odd parity. The 'RAST' is written in blocked BCD, even parity, 6 bits per character.

Table 17 summarizes the logical and physical segmentation of the magnetic tapes.

TABLE 17

Summary of Tape Format Physical and Logical Divisions

Tape Type	RAST	RAPT	PHAEST	ORPT
Format Type	Blocked BCD	Binary	Binary	Binary
Number of Orbits per Magnetic Tape	100	30	20	33 IMP-4 44 IMP-5
Number of Logical Records per Physical Record	57	102	200	40
Number of Words* per Physical Record	1881 [‡]	816	600	1000
Number of Words* per Logical Record	33	8	3	25
Total Number of Magnetic Tapes in IMP-4 Submission	2	6	9	5
<p>* XDS 930 binary, 24 bits per word.</p> <p>‡ Short records do occur, but only immediately before an EOF.</p>				

The data on all tapes are ordered so that time and PSC are monotonically increasing, with discontinuities only at points where no data was received or where the data quality* of a particular sequence was other than good or fair.

The following word-bit placement convention is used in the data format descriptions. The lowest word and bit number is located closest to the beginning of the physical record, the beginning of the file, and the beginning of the tape. Similarly, 'File 1' of a tape is located immediately after the load point marker at the beginning of that tape. Furthermore, the

* See GSFC X-563-69-292 section 2.7.

TABLE 18
RAPT LOGICAL RECORD SPECIFICATION

Item Number	Item Name	Location Within Logical Record		COMMENTS
		WORD	BITS	
1	Calibrate/Normal Flag	1	0	Value = $\begin{cases} 0, & \text{In Calibrate Mode} \\ 1, & \text{In Normal Mode} \end{cases}$
2	End of Orbit Flag	1	1	Value = $\begin{cases} 1, & \text{Normally} \\ 0, & \text{At end of orbit where all remaining logical records in the last physical record are filled with zeros.} \end{cases}$
3	Pseudo Sequence Count	1	2 thru 23	See Section 2.4.
4	Accumulator 7C Frame 2	2	0 " 11	See Tables 9 and 10.
5	Accumulator 7C Frame 6	2	12 " 23	
6	Accumulator 7C Frame 10	3	0 " 11	
7	Accumulator 7C Frame 14	3	12 " 23	
8.	Prescale Flag Frame 2	4	0 " 1	Value = $\begin{cases} 0, & \text{Not in Prescale Mode} \\ 1, & \text{D1D2D3D6 is prescaled} \\ 2, & \text{D1D2D6 is prescaled} \\ 3, & \text{Both D1D2D6 and D1D2D3D6 are prescaled.} \end{cases}$
9.	" " " 6	4	2 " 3	
10.	" " " 10	4	4 " 5	
11.	" " " 14	4	6 " 7	
12.	Data Quality Flag Frame 2	4	8	Flag Value = $\begin{cases} 0, & \text{All data items have good quality.} \\ 1, & \text{One or more items had fair quality; or one item had poor quality, so, all data items are filled, with ones.} \end{cases}$
13.	Data Quality Flag Frame 6	4	9	
14.	Data Quality Flag Frame 10	4	10	
15.	Data Quality Flag Frame 14	4	11	
16.	Geocentric Distance of Satellite	4	12 thru 20	In tenths of earth Radii
17.	Overlap elimination flag	4	21 " 23	A value of "5" indicates the elimination of overlap.
18.	PHA Duplicate event Flag			Value = $\begin{cases} 0, & \text{there is a record of this frame on the PHAEST.} \\ 1, & \text{There is not a record of this frame on the PHAEST, because there were no events collected during this frame.} \end{cases}$
	Frame 14	5	0	
19.	Frame 10	5	1	
20.	Frame 6	5	2	
21.	Frame 2	5	3	
22.	Accumulator 7A Frame 2	5	4 thru 13	See Tables 9 and 10
23.	Accumulator 7A Frame 6	5	14 " 23	
24.	Accumulator 7A Frame 10	6	0 " 9	
25.	Accumulator 7A Frame 14	6	14 " 23	
26.	Accumulator 7B Frame 2	7	0 thru 9	
27.	Accumulator 7B Frame 6	7	14 " 23	
28.	Accumulator 7B Frame 10	8	0 " 9	
29.	Accumulator 7B Frame 14	8	14 " 23	
30.	Sun Time	6, 7, 8,	10 " 13	In milli-seconds. Word 6 contains most significant part, and word 8 contains the least significant part.
				47

bit significance increases as the bit position number decreases; e.g., for a value stored completely in bits 9 through 14 of a word, bit 9 (when it is on) holds the value 2^5 , bit 10 holds 2^4 , and so on until bit 14 which represents 2^0 .

3.2 RAte Packed Tape--RAPT

The RAte Packed Tapes contain the S-T Accumulator readouts and related data exactly as telemetered from the spacecraft. As can be seen in Table 17 all physical records on the RAPT are 816 words in length, divided into 102 logical records of 8 binary packed words. Table 18 specifies the data item to word and bit correspondence.

3.2.1 S-T Accumulators

There are three Scaler-Timer accumulators: two 10-bit (7a and 7b) and one 12-bit (7c). Each S-T accumulator operates as a scaler until the high order bit is set, e.g. 512 counts in a 10-bit accumulator, then the accumulator ceases to accept data pulses and starts to operate as a timer which measures the residual accumulation time from a spacecraft clock. For the 10-bit accumulators the clock has a frequency of 100 Hz and for the 12-bit accumulator 400 Hz; whence for the nominal accumulation time of 4.8 seconds, the high order bit, once set for time-mode (T-mode), is not reset until the end of readout when the accumulators are always zeroed.

3.2.2 Sun Time

The sun time is the time interval in milliseconds starting at the beginning of channel 0 of frame 0 of the given sequence and ending at the first detection of the sun by the Optical Aspect sensor.

Table 19

RAST LOGICAL RECORD SPECIFICATION

Item Number	Item Name	Format *	Description
1	Day	I3	This Data pertains to the <u>Last</u> point of the interval from which the following rate averages were computed.
2	Hour	I2	
3	Minute	F4.1	
4	Chicago Sequence Count	I8	
5	Satellite Geocentric Distance in Earth Radii	F4.1	
6	D5/D6 analog Ratemeter Average Rate	E12.5	All Rate Averages are in counts/second
7	Accumulator 7B Frames 2 thru 14	E12.5	For specific detector coincidences see Tables 9 and 10.
8	Accumulator 7B, Frames 6 and 14	E12.5	
9	Accumulator 7A Frames 6 & 14	E12.5	
10	Accumulator 7B Frames 2 & 10	E12.5	
11	Accumulator 7A, Frame 10	E12.5	
12	Accumulator 7A, Frame 2	E12.5	
13	Temperature	F6.2	In Degrees Centigrade
14	Number of Good Frames	I3	Only frames in which all the Data qualities were 'Good' are used in computing rate averages
15	Total Number of Frames	I3	If a frame contains even one data quality below 'Good', it is discarded, or if an 'overlap' condition is encountered, the second CSC or poorer quality CSC is discarded. This item is the total of all types of frames encountered in the 15 sequence count interval.

* Each item is led by a space 1X.

TABLE 20

PHAEST LOGICAL RECORD SPECIFICATION

Item Number	Item Name	Location Within Location Record		Comments
		Word	Bits	
1.	PSC	1	0 thru 23	See Section 2.4
2.	PHA Accumulator 1	2	0 thru 7	See Tables 9 and 10.
3.	" " 2	2	8 " 15	
4.	" " 3	2	16 " 23	
5.	Range ID	3	0 " 2	See Section 2.
6.	Angular Sector	3	3 " 5	
7.	Frame Number	3	6 " 7	Instead of 2, 6, 10, and 14 we have respectively 0, 1, 2, 3.
8.	Data Quality Flag	3	8	Value = {0, all data qualities are good 1, at least one data quality was fair but none were lower than fair.
9.	Orbit Number	3	9 thru 15	Least significant part of orbit number (for orbits 1 through 127)
10.	Orbit Number	3	16	Most significant bit (for orbits 128 through 255.)
11.	PHA Accumulator 2	3	17	The most significant bit of item 3. (This bit was added to accomodate the 512 channel D2 PHA analyzer on IMP-5.)
12.	End of orbit flag	3	18 thru 23	Value = {1, during orbit 0, at end of orbit (the remaining logical records in the last physical record are filled with zeroes.)

TABLE 21
ORPT LOGICAL RECORD FORMAT

Word Number Within Logical Record	Parameter Name	Description and Comment
1	Pseudo Sequence Count	This is the PSC for which the following orbit data is applicable.
2	Coordinate recomputation flag.	If non zero, then items 13 and 15-18 were in error and have been corrected at the University of Chicago.
3	Geocentric Distance of Satellite	In thousandths of an earth radius.
4 5 6	Day of Year Hour of Day MSEC of Hour	Time for which orbit data is valid. (January 1 = day 1)
7	Satellite-Earth-Sun Angle	In thousandths of a degree.
8 9	In the geomagnetic reference frame: Geomagnetic Longitude of Satellite Geomagnetic Latitude of Satellite	In all the geomagnetic reference frames, the assume location of the north magnetic pole is 69.0° west longitude, 78.2° north latitude. In thousandths of a degree.
10 11 12	In the Solar Magnetospheric Coordinate System: X Coordinate Y Coordinate Z Coordinate	In thousandths of an earth radius.
13 14	Geomagnetic Longitude of the Sun Geomagnetic Latitude of the Sun	In thousandths of a degree.
15 16	Geocentric Longitude of the Satellite Geocentric Latitude of the Satellite	In thousandths of a degree.
17 18	Geocentric Longitude of the Sun Geocentric Latitude of the Sun	In thousandths of a degree.
19	Speed of Satellite	In meters/second
20	L, McIlwain Parameter	In thousandths of an earth radius.
21	B, Field Strength	In milligauss
22	B/B_0	Dimensionless x 100
23 24 25	Theoretical Geomagnetic Field in Solar Ecliptic Coordinate System: X Coordinate Y Coordinate Z Coordinate	In milligauss

3.3 RAte Summary Tape--RAST

The RAte Summary Tapes contain counting rates averaged over consecutive time intervals of 15 PSC's (~ 5 minutes) using only data of good quality. The last PSC in the period averaged over is assigned to the rate average. The physical and logical record size are given in Table 17.

Each logical record is generated with the following Fortran II format.

ITEM:	1	2	3	4	5	6 - 12	13	14	15
FORMAT	(1X, I3, 1X, I2, 1X, F4.1, 1X, I8, 1X, F4.1, 7 (1X, E12.5), 1X, F6.2, 1X, I3, 1H/I3)								

The item names, units, and other specifications are displayed in Table 19.

3.3.1 Exceptions to the Standard Format

When reading the data from the tape, the above format statement is used except when reading the first logical record of each orbit which logical record is a heading. The second logical record of each orbit, although written in the above data format is not a data line and contains the following substitutions:

- 1) ITEMS 1 through 4 contain the Day, Hour, Minute and PSC for the first good data of the orbit.
- 2) ITEM 5 contains the orbit number.
- 3) ITEM 6 contains the geocentric distance of the satellite in kilometers.
- 4) All other ITEMS are filled with zeroes.

Similarly the last logical record of an orbit does not contain experiment data, but has the following substitutions:

- 1) ITEMS 1 through 3 contain the time of the last good data of the orbit.
- 2) ITEM 4 = -1, thus acting as a sentinel flag for the orbit.

- 3) ITEM 6 contains the total number of frames in the orbit.
- 4) ITEM 11 contains the total number of frames used (only good quality) to compute the rate averages in the orbit.
- 5) ITEM 12 is superceded by ITEM 6.
- 6) All other ITEMS are filled with zeroes.

The last physical record of a file terminates at the end of the orbit contained in that file. Hence, the number of logical records in the last physical record is usually less than the normal 57.

3.3.2 Calibrate Mode

When the instrument is in calibrate mode all counting rates are zeroed, except the D5/D6 Analog Ratemeter.

3.3.3 Analog Ratemeter

Although the Analog Ratemeter alternates between the D5 and D6 (see telemetry formats), these modes are not mixed when averaging is performed for the RAST. The mode the instrument is in at the beginning of the interval is the mode for that entire interval; ie., if the satellite switches mode during the interval, the new mode readouts are discarded.

3.4 Pulse Height Analysis Event Summary Tape--PHAEST

These tapes contain, among other pertinent data, the pulse height analyzer accumulator readouts as telemetered by the spacecraft. Only events with associated data qualities of 'good' or 'fair' are recorded on these tapes. As stated in Table 17 all physical records contain 600 words, divided into 200 logical records of 3 binary packed words. Each logical record contains all the data for one event.

If no events are collected during a frame, then there is no record of that frame on the PHAEST.

Table 20 itemizes the data item to word-and-bit correspondence within a logical record.

3.5 ORbit Parameter Tape--ORPT

These tapes contain trajectory data furnished by GSFC.

Referring to Table 17 a physical record consists of 1000 binary packed words, divided into 40 logical records of 25 words. The complete set of orbit data contained in each logical record applies to the PSC appearing in that logical record.

Between consecutive logical records there normally is an increment of three PSC's (~ 1 min.). Table 21 contains the correspondence between data items and words within a logical record.

The parameter values are written in standard XDS 930 Integer format. That is, eight octal digits (one XDS 24-bit word) are allocated for each value. The most significant octal digit has only two bits since its leading bit (bit position zero of the word) represents the sign. If the sign bit is off (value: zero), the number is positive and represented in binary integer form with the most significant bit having the lowest bit position ('bit 1' is the lowest bit position). This is identical to the data representation used on the RAPT and PHAEST, except that every parameter now has a sign bit, and every value has exactly 23 bits. However, if the sign bit is on (value: one), the number is negative and represented in two's complement form.

4.

Format for the Counting Rate Plots on Microfilm

The plots were computer generated on a Cal/Comp 563 plotter with the vertical axis representing the rate in counts per second, and the horizontal axis representing a time period of 30 days beginning on the first day of a Bartels Solar Rotation and ending three days into the following Solar Rotation. The horizontal scale is one day per division, and the vertical logarithmic scale varies for each range interval. Every horizontal fiducial is labelled with the PSC and the day of year (January 1 = Day No. 1). The year is printed at the origin and whenever it changes. Each plotted point represents a rate averaged over 45 sequences.

The heading of each plot contains the satellite number*, the Bartels Solar Rotation number, the range interval expressed as detector coincidence, and the date of generation of the plot**.

Table 22 specifies the time and solar rotation intervals covered.

TABLE 22
Microfilm Data Coverage

IMP-No.	Bartel's Solar Rotation No.	Dates (UT)
1	1783 - 1790	11-27-63 to 5-29-64
2	1795 - 1802	10-4-64 to 4-5-65
3	1804 - 1830	5-29-65 to 5-2-67
4	1831 - 1856	5-24-67 to 4-29-69
5	1859 -	6-21-69 to (> 3/71)

* Plots are being submitted for IMP 1, 2, 3 and 4 in microfilm form. (One roll of microfilm per satellite.)

** This date has no connection with the data.

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List of Tables

<u>Table</u>	<u>Title</u>
1	Instrument Weight and Power
2	Composition Telescope Absorbers
3	IMP-4 Electron Telescope Absorbers
4	IMP-4 Counting Rates
5	IMP-4 Composition Telescope Energy Ranges
6	IMP-4 Electron Telescope Energy Ranges
7	IMP-5 Counting Rates
8	IMP-5 Energy Ranges
9	IMP-4 Telemetry Format
10	IMP-5 Telemetry Format
11	IMP-4 Detector Thresholds
12	IMP-4 PHA Calibration
13	IMP-4 Conversion Factors
14	IMP-4 Satellite History
15	IMP-5 Detector Thresholds
16	IMP-5 PHA Calibration
17	Summary of Tape Format Physical and Logical Divisions
18	Rapt Logical Record Specifications
19	Rast Logical Record Specifications
20	PHaest Logical Record Specifications
21	Orpt Logical Record Specifications
22	Microfilm Data Coverage

FIGURE CAPTIONS

- Figure 1 Location and orientation of University of Chicago experiment on IMP-4, showing position of acceptance cones of the composition and electron telescopes.
- Figure 2 Location and orientation of University of Chicago experiment on IMP-5. Note that there is no electron telescope on this experiment. Only the 55° acceptance cone of the telescope is indicated (see Figure 4).
- Figure 3 Schematic drawing of detector layout in IMP-4 Composition and Electron telescopes. Detector housings and mountings are not shown.
- Figure 4 Schematic drawing of Composition telescope on IMP-5.
- Figure 5 Simplified logic diagram of the IMP-4 experiment. This diagram shows only the normal mode operation of the instrument.
- Figure 6 Simplified IMP-5 logic diagram for normal mode operation.
- Figure 7 Orientation of the angular sectors for IMP's 4 and 5.
- Figure 8 Temperature history of IMP-4 experiment. The semi-sinusoidal variations are due to seasonal variation of the distance to the sun, while the overall rising trend is due to ultra-violet degradation of white thermal paint on the experiment facet.
- Figure 9 Location of IMP-4 in flight calibrator pulsar peaks throughout the mission. Note increasing spread of peaks in D4 PHA as the experiment aged.
- a) D1
 - b) D2, and
 - c) D4

The University of Chicago
Composition Telescope, IMP-4

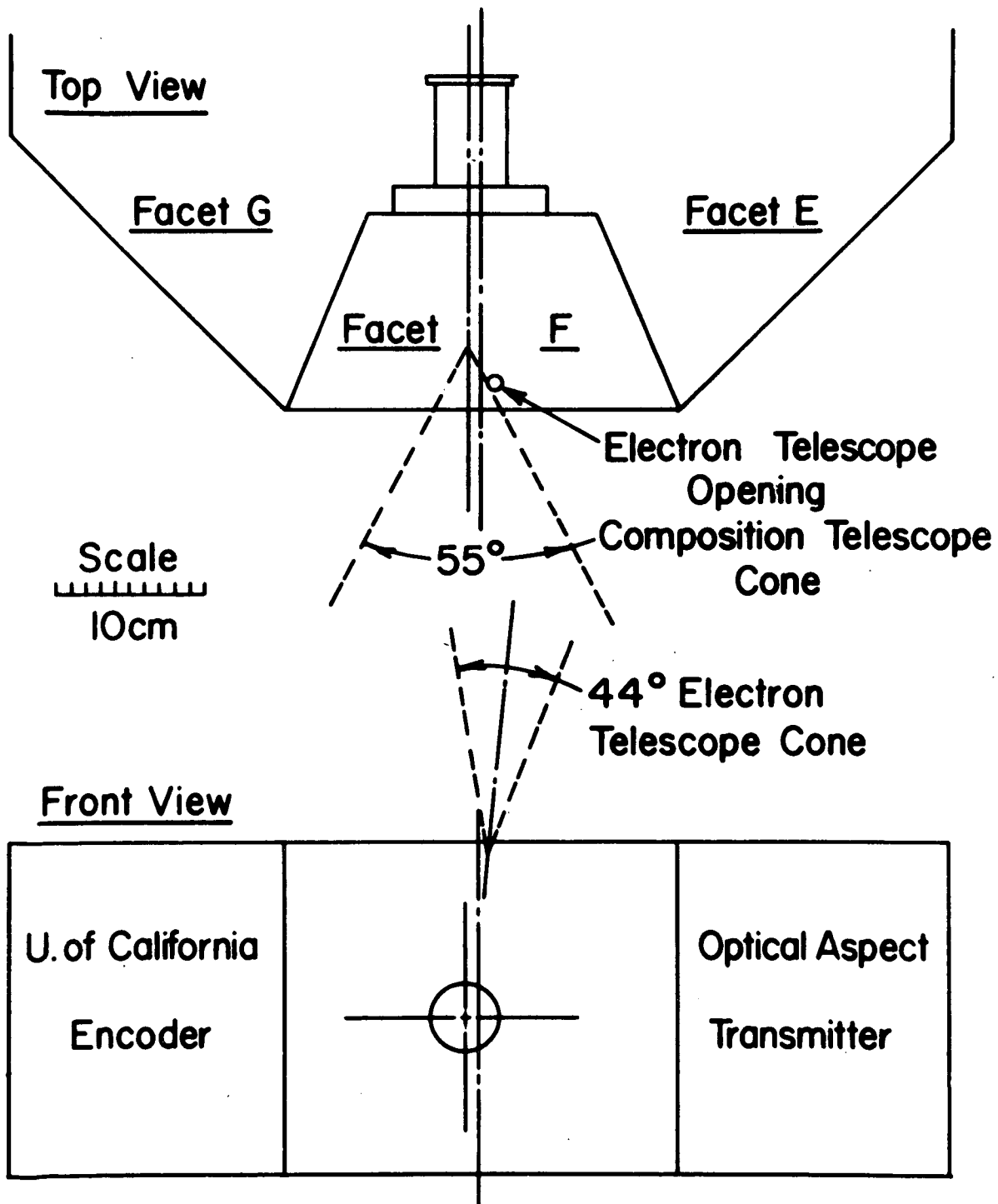


Figure 1

IMP - 5

Location and Orientation of University of Chicago Experiment

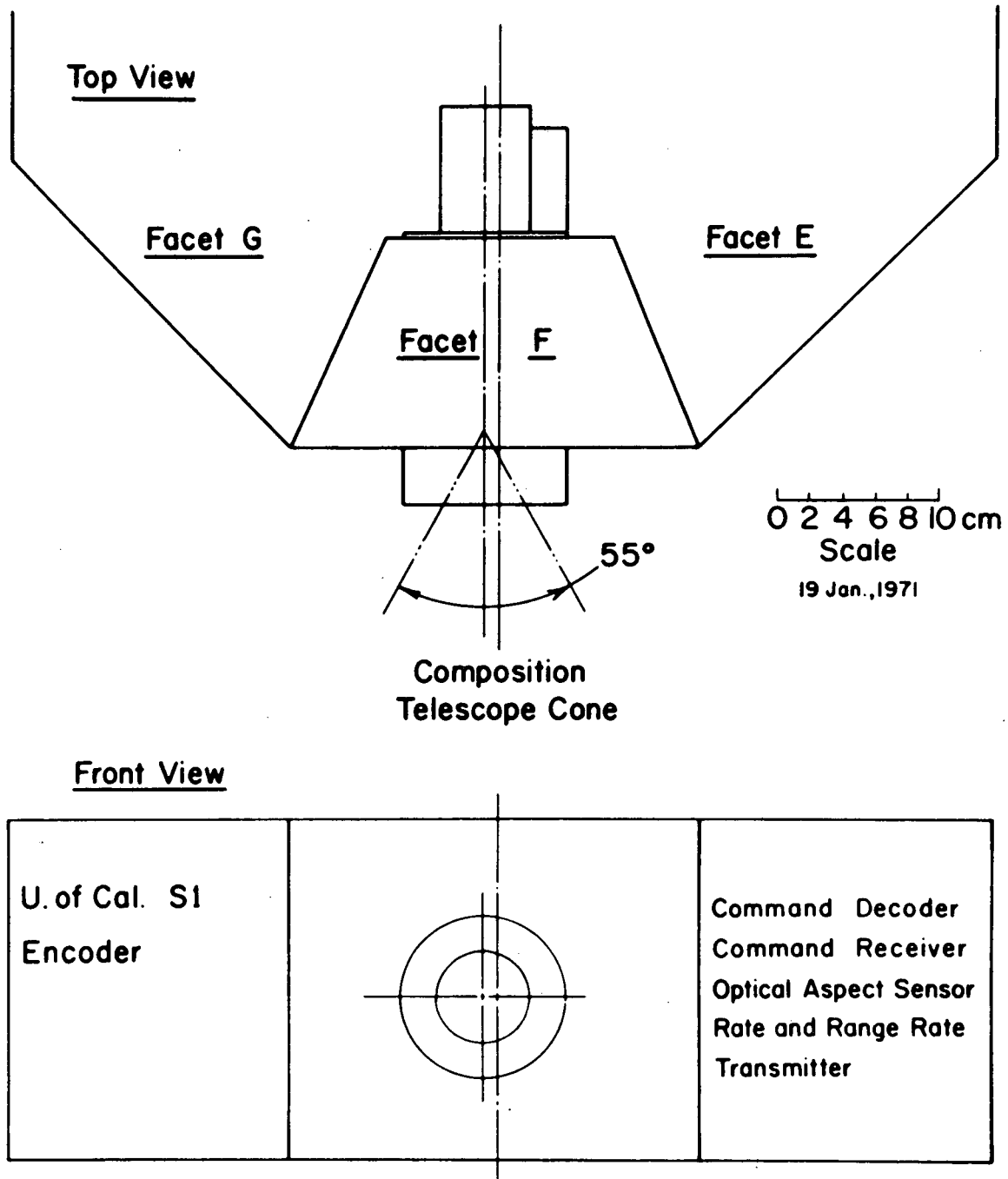
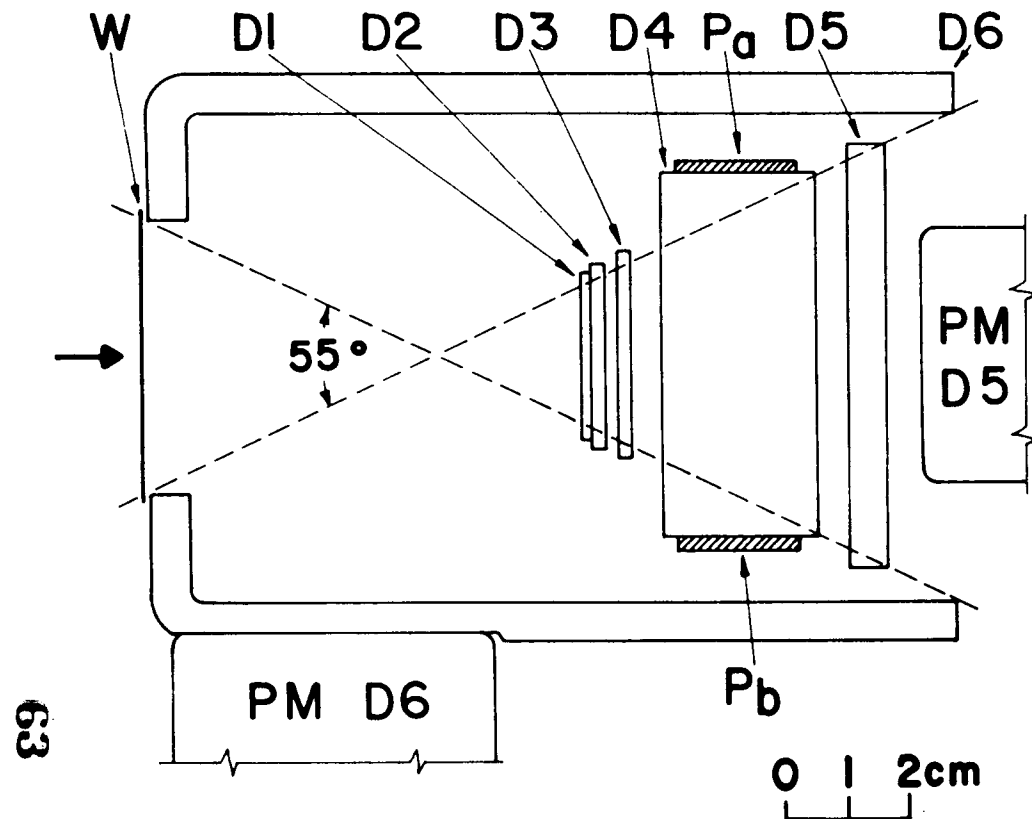


Figure 2



Composition Telescope

W — Al-Mylar Window

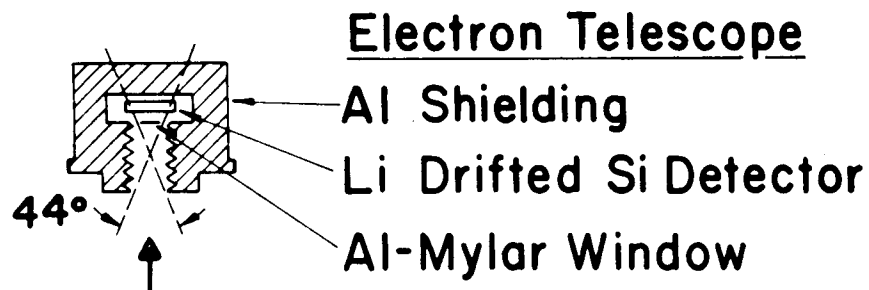
D1 }
D2 } Li-Drifted Si
D3 } Detectors

D4 — CsI(Tl) Crystal
Viewed by Pa, Pb
Au-Si Photo Diodes

D5 — Plastic Scintillator

D6 — Anti-Coincidence
Plastic Scintillator

PM — Photomultiplier

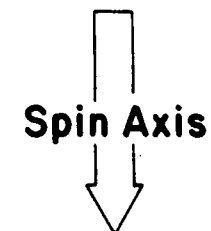


Electron Telescope

Al Shielding

Li Drifted Si Detector

Al-Mylar Window



IMP-4 The University of Chicago

Figure 3

Composition Telescope

IMP 5 The University of Chicago

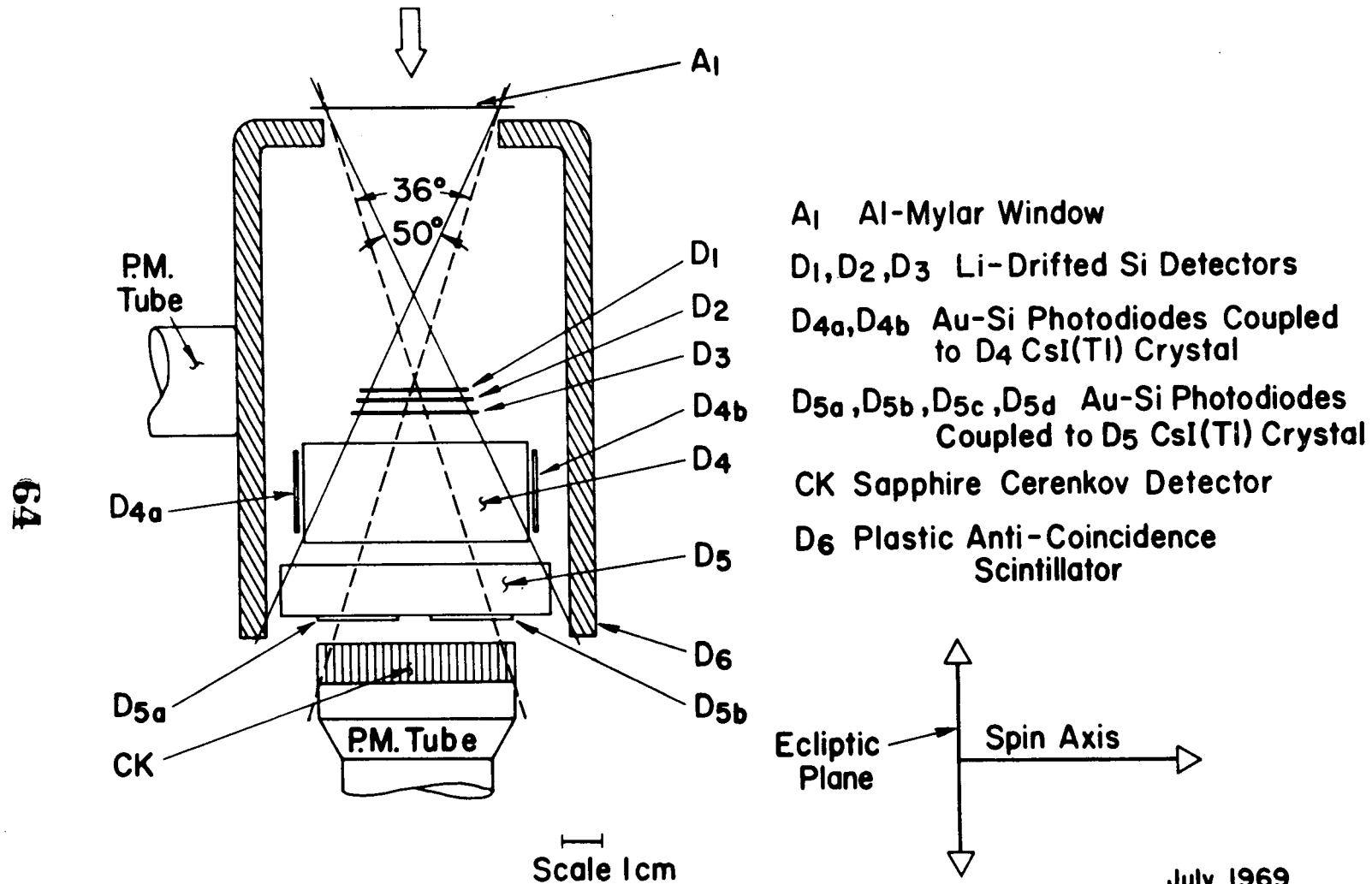
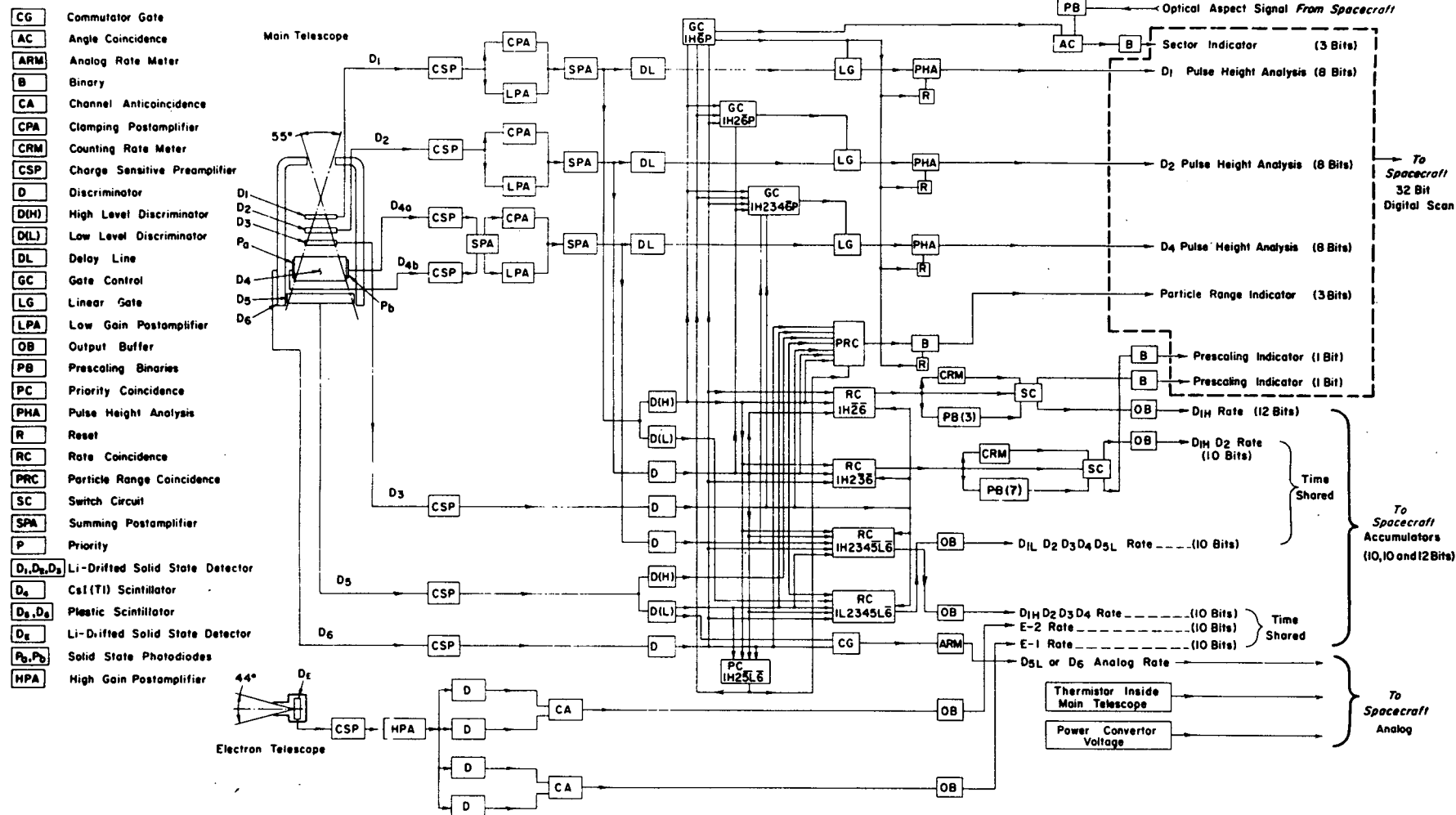


Figure 4

IMP-4 UNIVERSITY OF CHICAGO EXPERIMENT



JS 9-8-70-6

Figure 5



IMP 5 University of Chicago Experiment

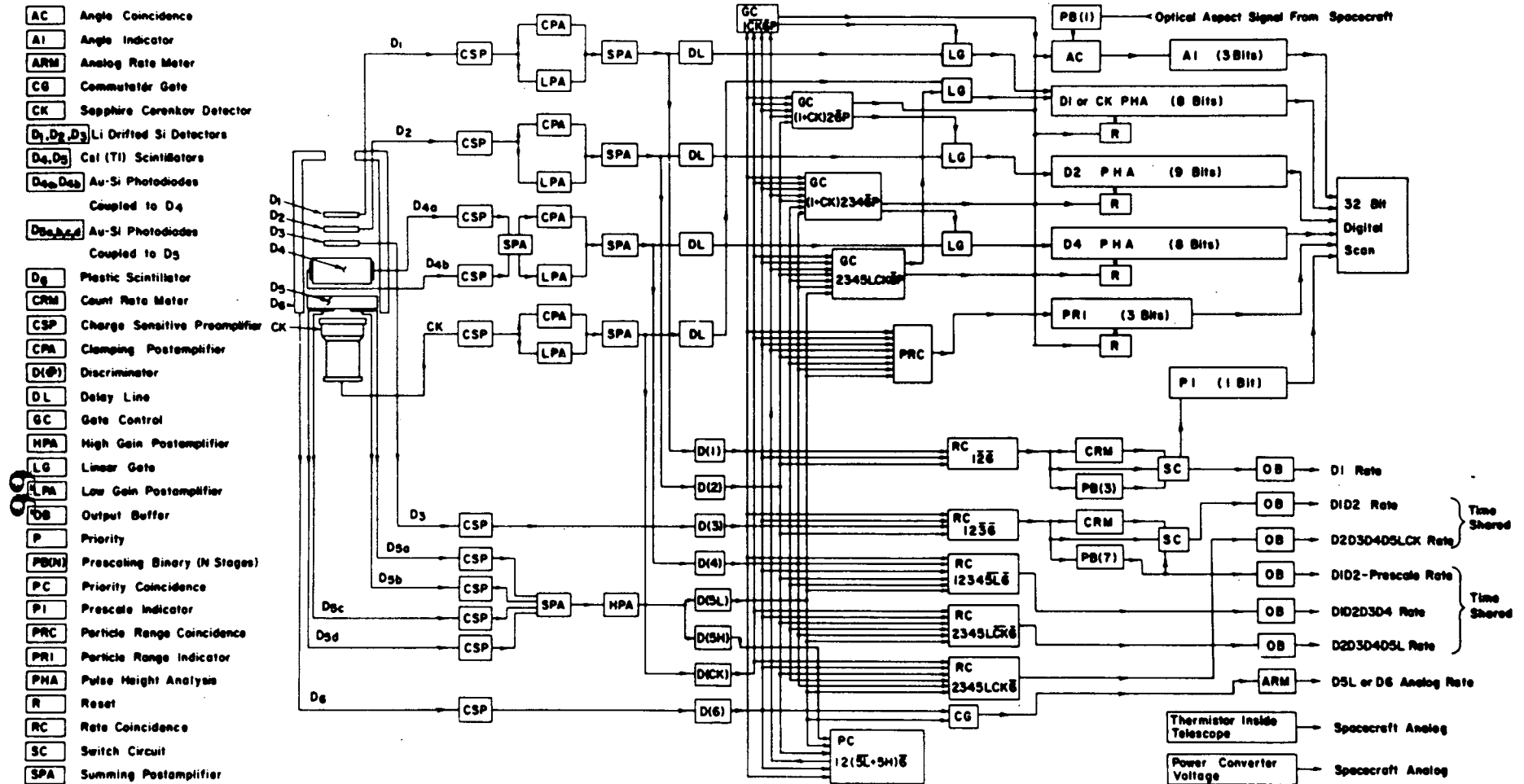


Figure 6

Angular Sector Orientation of The University of Chicago Composition Telescopes on IMP-4 and IMP-5

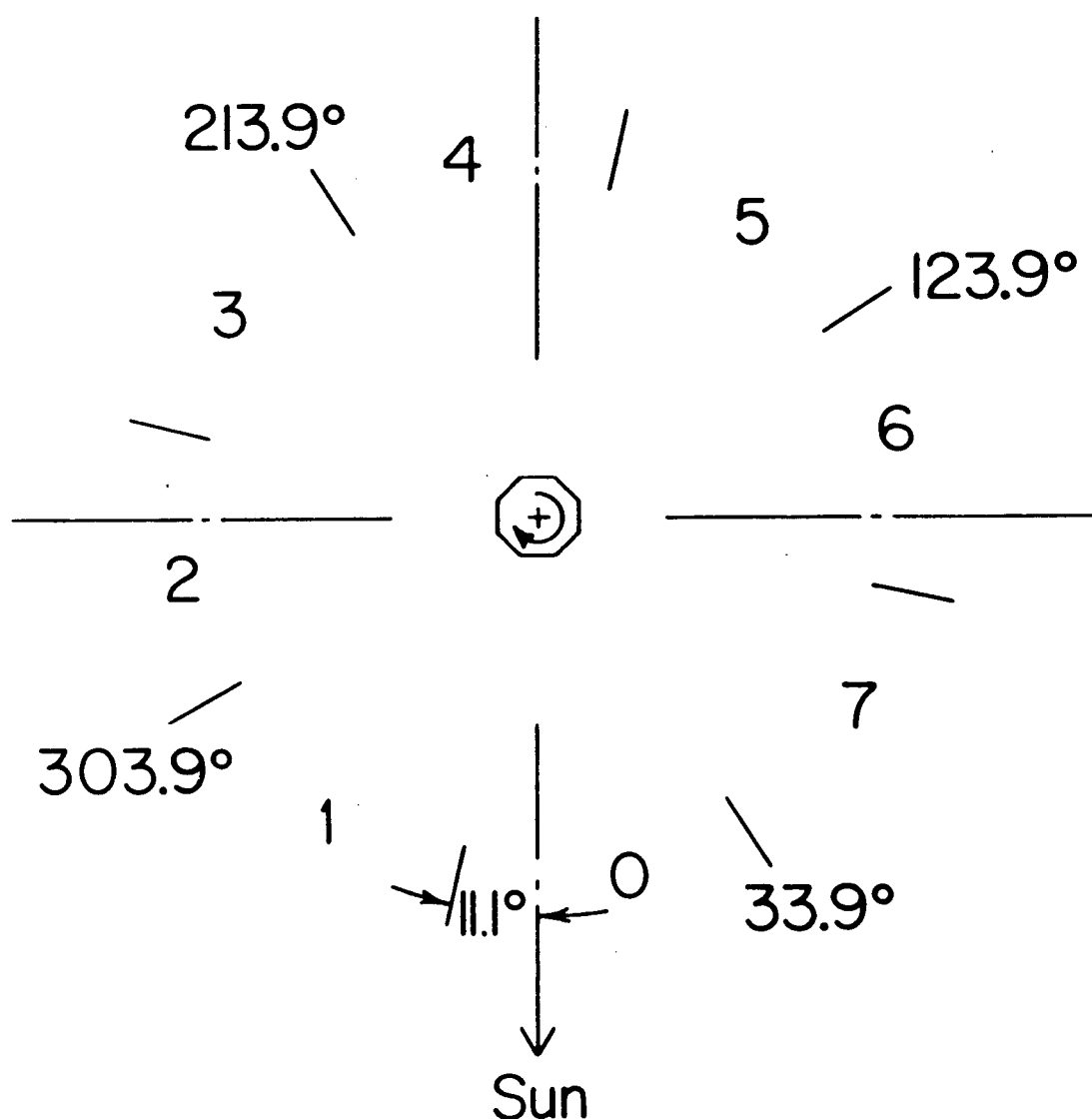


Figure 7

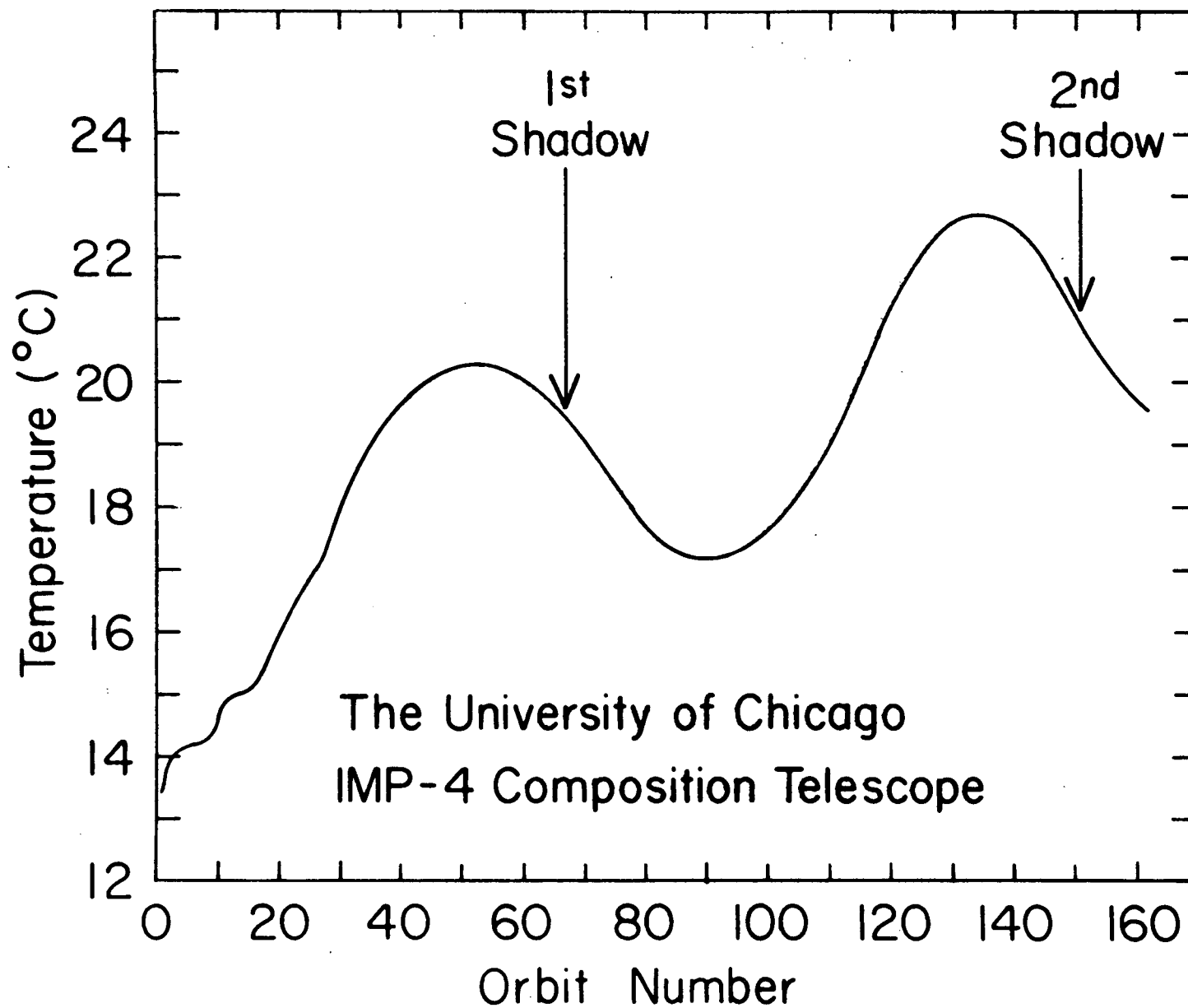


Figure 8

D_I Calibrate Mode Peaks

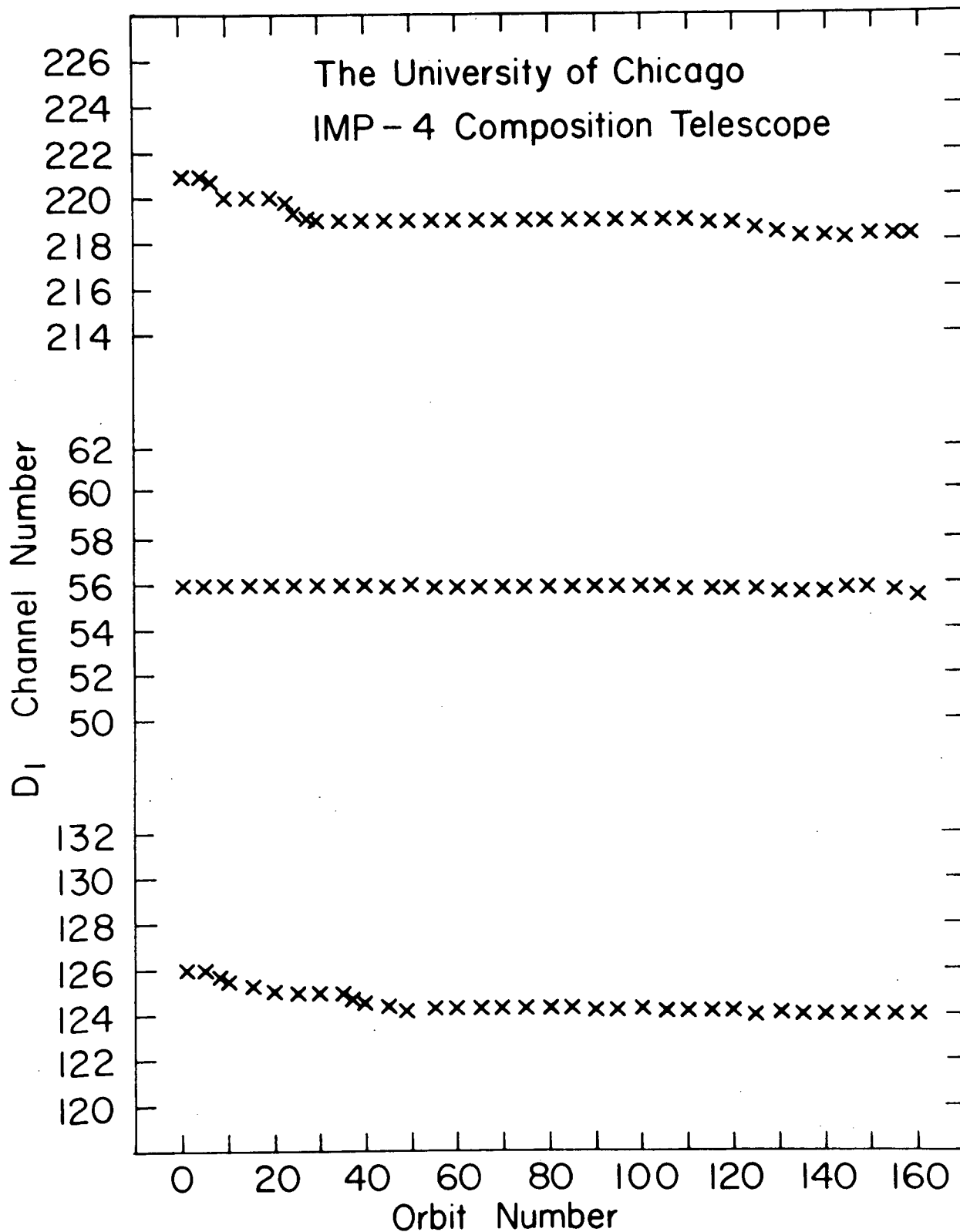


Figure 9a

D₂ Calibrate Mode Peaks

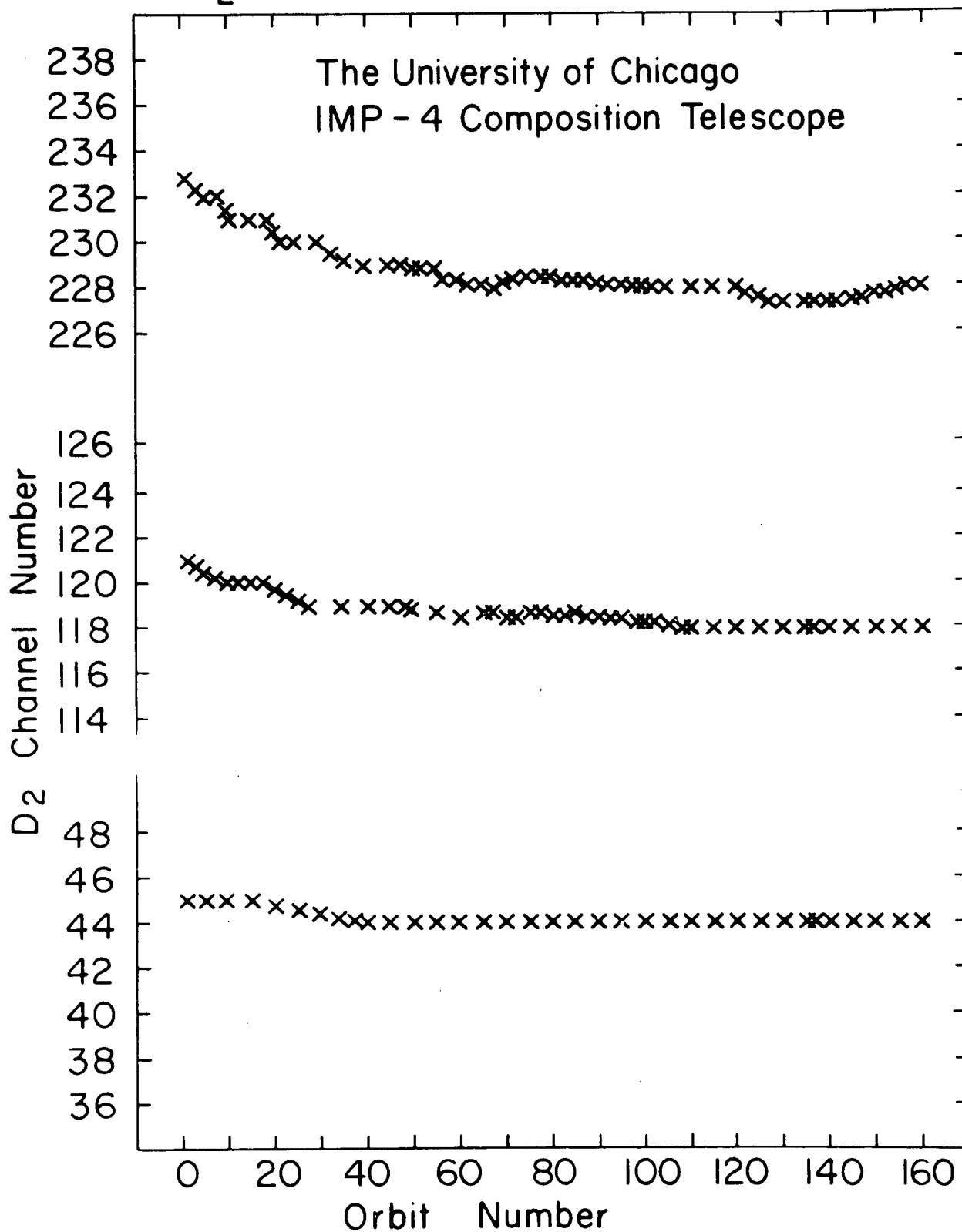


Figure 9b

D4 Calibrate Mode Peaks

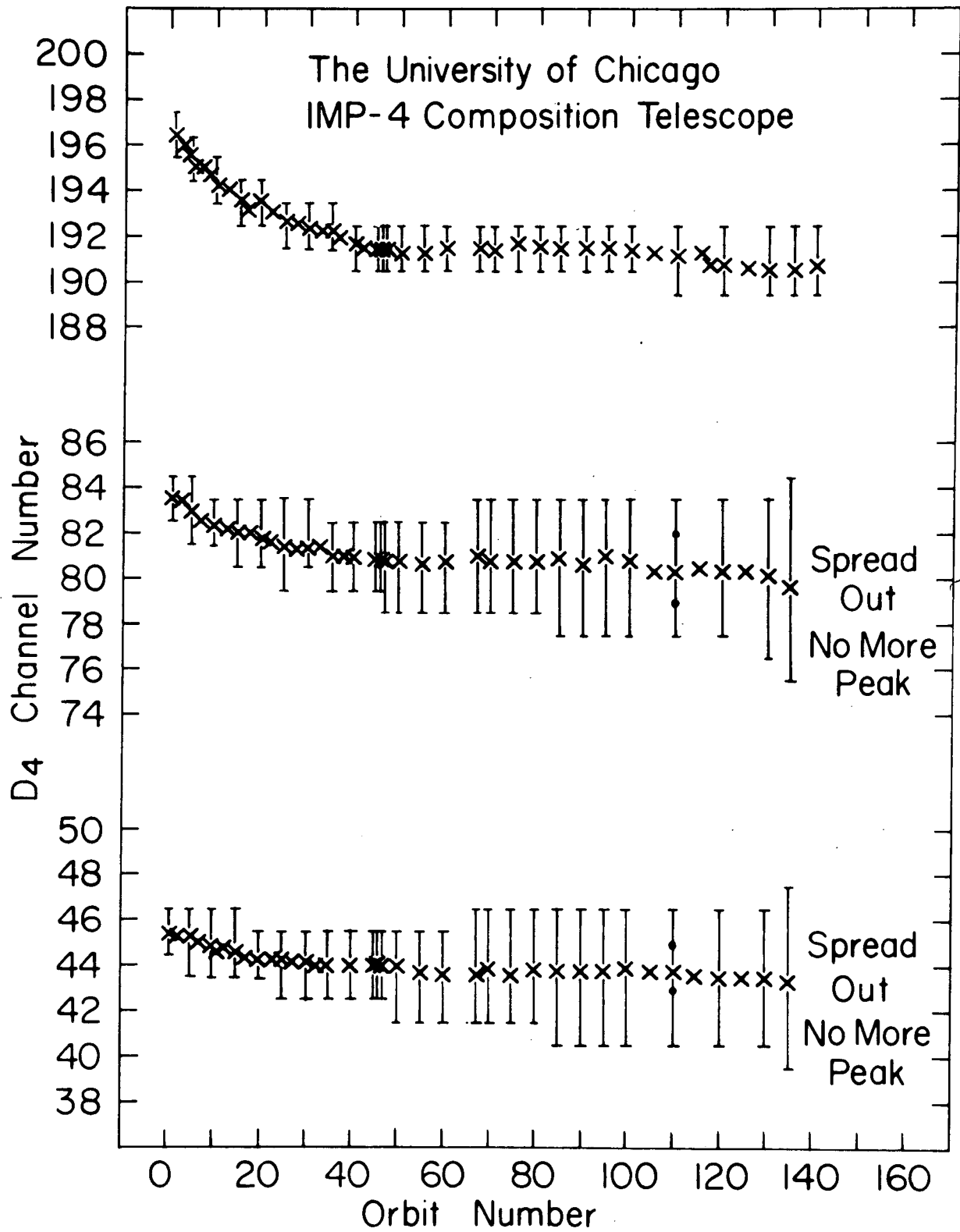


Figure 9c